Space Shuttle Program

CR 134302

MSC-03309

FINAL SUBMITTAL

Engineering and Development Plan for Phase C/D

Volume III. Booster System

Contract NAS9-10960
DRL M010, DRL Line Item 14
DRD SE001M
SD 71-102-3
25 June 1971

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Space Division • North American Rockwell 12214 Lakewood Boulevard, Downey, California 90241

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(MSC-03309)

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SPACE SHUTTLE
ENGINEERING AND DEVELOPMENT PLAN

Volume III
Booster System

Approved by

B. Hello
Vice President and General Manager
Space Shuttle Program

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DRL M010, DRL Item 14
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Space Division • North American Rockwell 12214 LAKEWOOD BOULEVARD • DOWNEY, CALIFORNIA 90241

FOREWORD

This plan is one of a family of program plans that establish, as applicable, requirements and prospective implementation approaches for the conduct of Phase C (Design) and Phase D (Development and Operations) of the Space Shuttle Program. With the exception of the cost data, which appear in the Cost and Schedule Estimates Plan only, each plan has been prepared in accordance with the specific contract requirements described in the Contract NAS9-10960 Statement of Work, Paragraph 4.7 and Appendix A, Data Requirements. These plans are as follows:

Title	Volume	SD No.	MSC No.
Program Management Plan for Phase C/D	One volume	SD 71-101	MSC-03308
Engineering and Development Plan for Phase C/D	I. Shuttle System II. Orbiter System III. Booster System	SD 71-102-1 SD 71-102-2 SD 71-102-3	MSC-03309
Operations Plan for Phase C/D	I. Shuttle System II. Orbiter III. Booster	SD 71-103-1 SD 71-103-2 SD 71-103-3	MSC-03310
Facility Utilization and Manufacturing Plan for Phase C/D	I. Orbiter II. Booster	SD 71-104-1 SD 71-104-2	MSC-03311
Preliminary Test Plan for Phase C/D	I. Shuttle System II. Orbiter III. Booster IV. Shuttle Support Equipment V. Shuttle Software	SD 71-105-1 SD 71-105-2 SD 71-105-3 SD 71-105-4 SD 71-105-5	MSC-03312
Logistics and Maintenance Plan for Phase C/D	One volume	SD 71-106	MSC-03313
Program Cost and Schedule Estimates Plan for Phase C/D	One volume	SD 71-107	MSC-03314

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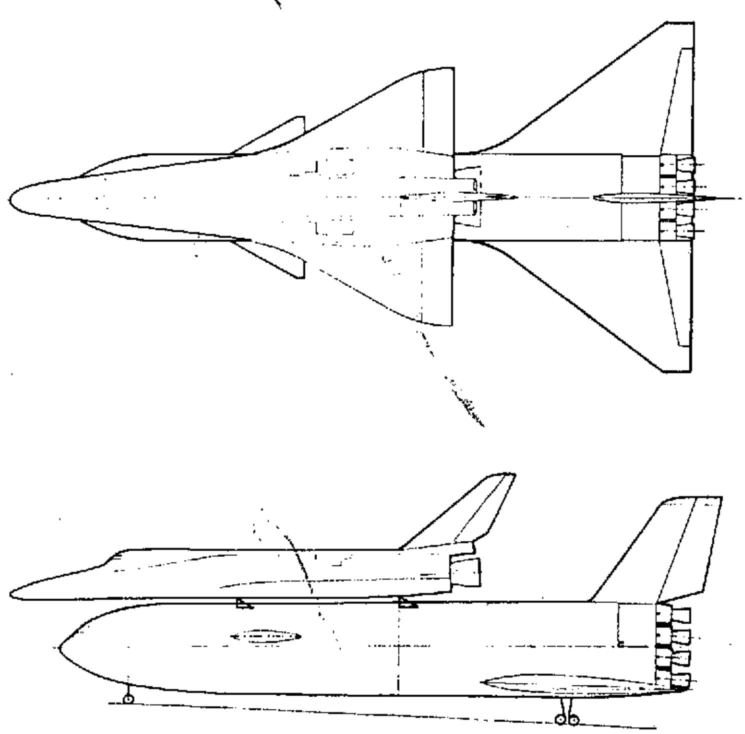
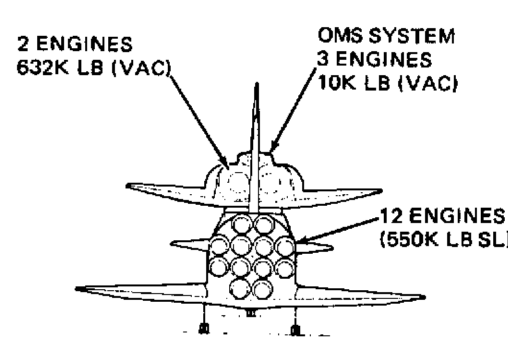
PREFACE

The objective of the Space Shuttle Program is to provide a low-cost space transportation system for placing and retrieving payloads in earth orbit. The first manned orbital flight is scheduled for April 1978. To achieve this goal, a reusable space shuttle system capable of a rapid turn-around, airline-type ground operation has been defined, satisfying as a minimum three basic missions: (1) 100-nautical-mile due-east circular orbit originating from a latitude of 28.5 degrees north, (2) a 55-degree inclination, 270-nautical mile earth orbit, and (3) a 100-nautical mile south polar circular orbit.

To accomplish these missions, a two-stage launch vehicle (shown below) has been defined, which is capable of delivering into orbit one stage with its payload. Each stage is capable of atmospheric entry and return to a designated landing site. The vehicle features moderate acceleration levels, a shirtsleeve cabin environment and quick turnaround capability. Operational facilities and system support equipment complement the flight vehicle.





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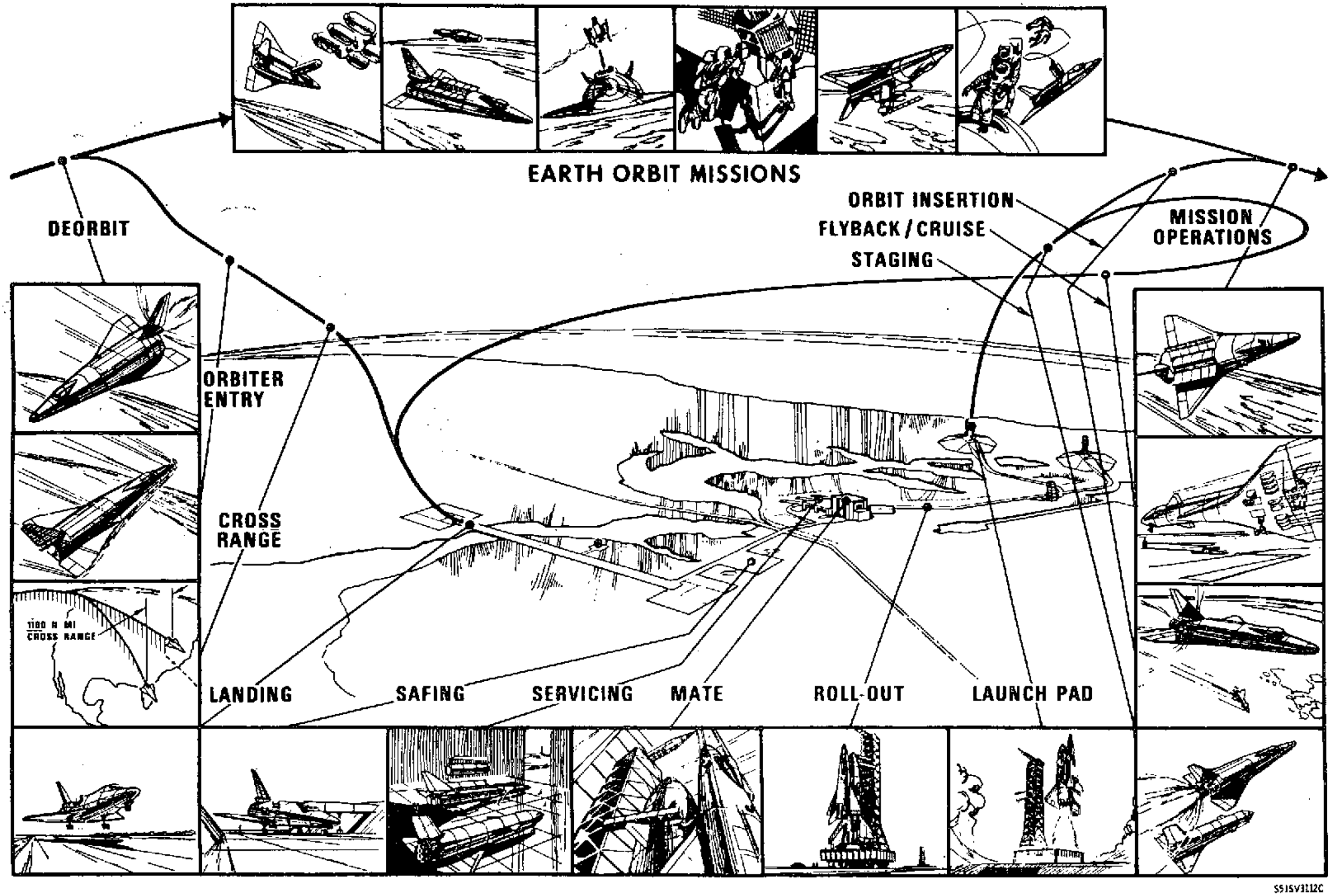
The booster and the orbiter are reusable delta-wing vehicles. The booster is equipped with 12 main rocket engines, an external heat shield to withstand the temperatures of boost and suborbital entry, and deployable airbreathing engines for cruising back to the launch site. The orbiter is equipped with two main rocket engines, orbital maneuvering rocket engines, an external thermal protection system to withstand the temperatures of boost and orbital entry, and deployable air-breathing engines installed for specific missions. The operations facility will provide for preflight readiness checkout, payload installation, and launch control, as well as primary landing sites and facilities for vehicle turnaround and necessary servicing. Shuttle support equipment includes all equipment required to check out, service, handle, and launch the flight vehicles.

The significant elements of these missions, as shown in the following figure, are ground operations, launch, and staging of the two vehicles. After staging, the first stage (booster) returns to the launch area while the second stage (orbiter) attains the prescribed insertion orbit after a series of orbital maneuvers. The second stage (orbiter) then delivers or retrieves its payload, enters the atmosphere, acquires the landing site, and completes the approach and landing. Safing operations are completed on each vehicle at the landing area preparatory to the turnaround cycle ground operations. Subsequent to payload installation in the orbiter, the orbiter is mated with the booster, and the mated system is made operationally ready and transported to the launch area for a new mission.



Elements of Space Shuttle Operations

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ILLUSTRATIONS

1.0 INTRODUCTION

The Space Shuttle System Engineering and Development Plan is divided into three volumes:

1. Volume I, Space Shuttle System.

2. Volume II, Orbiter System.

3. Volume III, Booster System.

Volume I defines the requirements for the total system development and Volume II defines the requirements for development of the space shuttle orbiter system. This volume, Volume III, defines the engineering requirements for the development of the space shuttle booster system, including the air vehicle, its associated support equipments, and the identification of the supporting facilities and operational support functions.

System elements of the space shuttle including the air vehicles and their associated support equipment will be designed to meet the performance, design, and interface requirements as specified in the Space Shuttle Specification and the Booster System Specification.

1.1 PURPOSE

The purpose of Volume III of the Engineering and Development Plan for the Space Shuttle Phase C/D Program is to establish the overall engineering and development requirements for the space shuttle booster system, and to identify potential technical problems and alternative approaches to minimize or resolve the problems.

1.2 SCOPE

The Booster System Engineering and Development Plan identifies, defines and interrelates the engineering tasks and test requirements required for the successful design development of the booster vehicle and its associated support equipment. Within this activity, system technical products, including booster operational system elements, test articles, models, and mockups are identified. General engineering and design requirements, which include the engineering processes and definition of requirements of reliability, maintainability, safety, quality assurance, etc., are described in Volume I since these functions and services are common to the orbiter and booster systems.

The time span covered in this plan is from Phase C go-ahead through Phase D development, terminating after the last mated flight identified as a development flight.

2.0 BOOSTER SYSTEM

The system elements that comprise the space shuttle system are described in the Foreword. This section defines the products that the booster system program is required to produce during the Phase C/D time period.

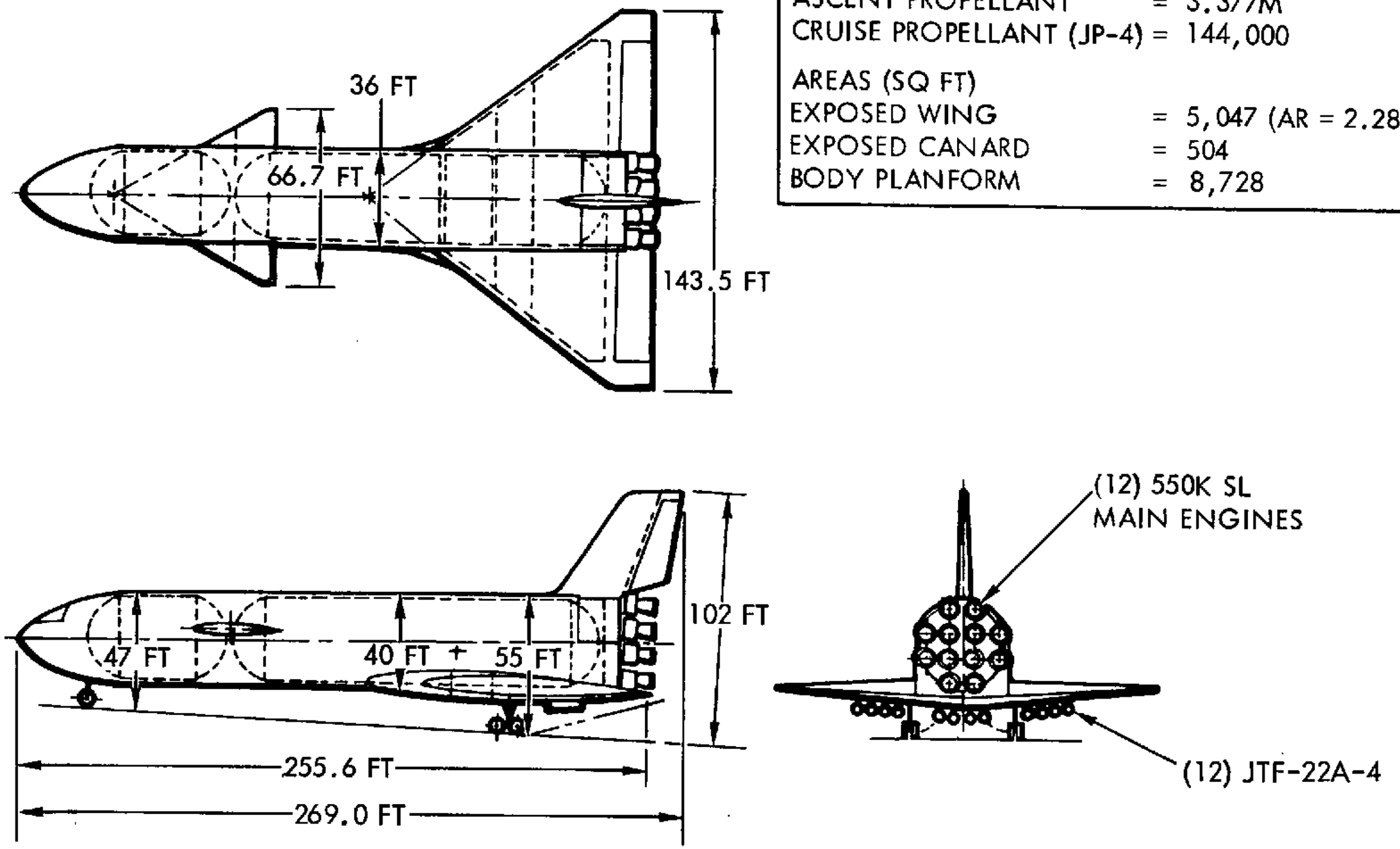
2.1 BOOSTER SYSTEM ELEMENTS

The major booster system products to be developed will include the operational booster air vehicle and its associated support equipment, including booster-orbiter common support equipment assigned to the booster contract for development, and the major test articles to support and verify the design development effort.

As shown in Figure 2-1, the Phase B baseline booster vehicle configuration has cylindrical tanks that contain the launch propellants and serve as the structural backbone. Surrounding the basic body structure is an outer heat shield assembly that provides not only the protective layer against aerodynamic heating but also provides an aerodynamic surface for the body. This aerodynamic surface varies from a round body-section from the nose to the delta wing, which is attached to the underside of the body structure. The delta wing in conjunction with its elevons, the pivotal canards, and the vertical tail provides the stability and control for both supersonic and subsonic flight.

For the vertical launch, mated with the orbiter, the booster thrust is provided by 12 main propulsion engines with a nominal thrust of 550,000 pounds per engine burning liquid hydrogen and oxygen. To minimize base area the engines are arranged in a cross in the aft end of the vehicle.

Control of vehicle attitude during the powered ascent is provided by gimballing the main engines for thrust vector control. Subsonic cruise, either for flyback after a space mission or for ferry flight, is provided by 12 air-breathing engines mounted in nacelles that are normally stowed within the wing and body structure envelope during the vertical flight and entry down to 20,000 feet altitude. To perform the powered cruise in normal horizontal flight the air-breathing engines are lowered into the air stream. Landing is accomplished using a conventional tricycle landing gear, including two four-wheel bogie main landing gear assemblies and a dual-wheel steerable nose gear assembly.



WEIGHT (LB)	
BOOSTER-LIFT OFF	= 4.188M
ASCENT PROPELLANT	= 3.377M
CRUISE PROPELLANT (JP-4)	= 144,000
AREAS (SQ FT)	
EXPOSED WING	= 5,047 (AR = 2.289)
EXPOSED CANARD	= 504
BODY PLANFORM	= 8,728

Figure 2-1. Basic Configuration, B-9U Booster

The booster incorporates an orbiter mating and separation system on its top surface to support the orbiter during vertical flight and to perform the separation of the two vehicles at its staging point.

Vehicle control and on-board function and configuration management are achieved through the integrated avionics subsystem (IAS) group. IAS provides guidance, navigation, flight control, data integration, communications, crew interfaces, and testing of all subsystems. Overall integration is provided by the data management system through the main digital data bus.

The subsystem groups of the booster vehicle include:

1. Structural subsystem group, including body structure, aerodynamic surfaces, the thermal protection system, and landing system.

2. Propulsion subsystem group, including main propulsion, attitude control, and air-breathing propulsion.

3. Avionics subsystem group, including guidance, navigation, and control; data control and management; displays and control; communications; and software.

4. Environmental control and life support subsystem group, including environmental control and life support and flight personnel provisions.

5. Power subsystem group, including auxiliary power unit and hydraulic and electrical power generation, distribution, and control.

These subsystem groups are presented in the Contract WBS as level 4 and the elements of the subsystem groups as level 5.

In order to support the booster vehicle to perform its mission objectives, support equipment (SE) has been identified in the following areas:

1. Launch support.

2. Checkout.

3. Handling and transportation.

4. Servicing.

5. Training.

6. Maintenance.

Major test articles that have been identified for the development program include the static, fatigue, and dynamic structural test articles, propulsion test articles, avionics test articles, flight control, and crew cabin/environmental control and life support test articles. Further definition of these test elements are presented in Section 4.2.3 and in Volume III of the Preliminary Test Plan.

2.2 SUMMARY DEVELOPMENT LOGIC

The summary development logic is presented in Figure 2-2. It displays the major constraints to the engineering and development function. The total engineering and development program will be structured to support delivery of the products with sufficient testing and qualification to verify integrity and performance capability for its intended use. This intended use will be a horizontal individual booster flight test, a mated vertical flight test, and operational flight.

3.0 PERFORMANCE AND OPERATIONAL REQUIREMENTS

The performance and operational requirements for the space shuttle system are defined in Volume I, Section 3.1. In addition to those requirements listed in Volume I, the requirements listed in the following paragraphs are applicable to the booster system.

3.1 GENERAL REQUIREMENTS

1. The booster vehicle shall be baselined to have go-around capability.

2. The booster vehicle shall have a two-man flight crew and shall be flyable under emergency conditions by a single crewman.

3. The booster crew environment shall be shirtsleeve.

4. Integrated vehicle vertical takeoff and individual vehicle horizontal landing shall be the vehicle mode of operation.

5. 550,000-pound sea level thrust bell-type engines will be baselined in the booster vehicle.

6. JP fuel will be baselined for all air-breathing engines.

7. All subsystems except primary structure and pressure vessels shall be designed to fail operational after the failure of the most critical component and to fail safe for crew survival after the second failure. Electronic systems shall be designed to fail operational after failure of the two most critical components and to fail safe for crew survival after the third failure.

8. Launch trajectory load factors shall not exceed 3 g's and entry trajectories shall not exceed 4 g's for the booster.

9. The booster and orbiter shall be designed for maximum interchangeability (common components and spares to be interchangeable).

10. The main propulsion system of the booster and orbiter shall be series burning.

11. A single engine out on the booster shall permit nominal mission continuation; on the orbiter, a safe abort capability.

12. Landing characteristics and handling qualities shall not require skills more demanding than those required for operational land-based aircraft.

13. The design should provide the capability to check out the vehicles in a mated and unmated configuration.

14. There shall be no propellant cross feed between the orbiter and the booster.

15. The propulsion system shall be capable of safe shutdown at any time.

16. Capability to deplete propellants prior to landing shall be provided.

17. The booster shall have the capability to land horizontally on runways no longer than 10,000 feet (sea level on a standard day).

3.2 REQUIREMENTS DOCUMENTATION

The space shuttle booster system will be designed to meet the requirements contained in the documents specified in Volume I, Section 3.2.

4.0 SYSTEM DEVELOPMENT REQUIREMENTS

This section identifies and relates the engineering activities required for the design and development of these products against the booster performance/design requirements.

4.1 BOOSTER SYSTEM DEVELOPMENT LOGIC

The development of the booster system during Phase C/D is governed by the schedule presented in Section 7, Figure 7-1. This schedule is based upon the booster system development program logic network presented in Figure 4-1. This logic network presents the sequence and dependancy of each of the development major events necessary for the successful development of the booster system. The events presented are keyed to the major program milestones, initial configuration design freeze, final configuration design freeze (preliminary design review), subsystem definition design freeze (critical design review), start of the horizontal flight test program, first mated orbital flight, and system operational readiness.

4.1.1 Preliminary Design

At contract go-ahead, NASA will provide the contract data package specified in Section 3.2, which forms the basis for the contractor engineering design development effort. Based upon the shuttle system and booster CEI specifications, the boost vehicle will be resynthesized to update the Phase B configuration. In performing this task, the orbiter vehicle requirements will be coordinated with the orbiter contractor to establish the booster-orbiter size relationship and staging conditions to achieve the goals of least cost, least development risk, and maximum safety in the space shuttle system. The preliminary design effort also includes updating the Phase B preliminary design configuration, profile and general arrangement drawings, redefinition of aerodynamic, aerothermodynamic and performance characteristics, and weight estimates. Completion of these tasks provides the basis for booster initial configuration freeze. During this period other engineering tasks necessary for supporting the preliminary design review (PDR) will be initiated. Some of the major tasks will be: implementation of the interface control plan, updating of the booster vehicle wind tunnel test plan, identification of additional trade studies, and the initiation of subsystem advance development testing.

After the initial booster vehicle configuration envelope is defined, this data will permit updating the wind tunnel model test articles, initiating the Phase C wind tunnel testing, initiating the updating of the booster subsystems and the booster CEI specification, and initiating preparation of interface control documents (ICD's).

The wind tunnel test program will determine the booster aerodynamic characteristics, including heating, for both the booster mated with the orbiter and the booster alone. The flight spectrum from lift-off, ascent flight, entry, and subsonic cruise will be thoroughly investigated. Data resulting from the wind tunnel test will be forwarded to both the preliminary design function and the subsystem design functions. Using the wind tunnel data for both the booster and orbiter, the preliminary design function will continue the task of optimizing the booster configuration and in conjunction with the orbiter contractor solidify the booster-orbiter interface requirements; i.e., staging conditions, size relationship of the booster to orbiter, external configurations of the booster and orbiter, mass properties relationship of the orbiter and booster, and the performance of the mated vehicles.

The updating of the booster subsystem preliminary design will include:

1. Revising existing drawings and schematics to conform to program requirements.

2. Performing identificable trade studies within the subsystems to minimize cost and reduce schedule impact.

3. Increasing reliability through failure modes, effects, and criticality analysis (FMECA).

4. Reducing development risks by performing risk assessment.

5. Providing a safe vehicle through hazard analysis.

6. Maximizing commonality between the orbiter and booster through joint evaluation and design requirements.

7. Ensuring a maintainable vehicle by performing maintainability evaluation and providing for supportability through logistics analysis.

During the preliminary design period, critical long lead time items will be identified and, with NASA's approval, material procurement will be initiated to support the development program.

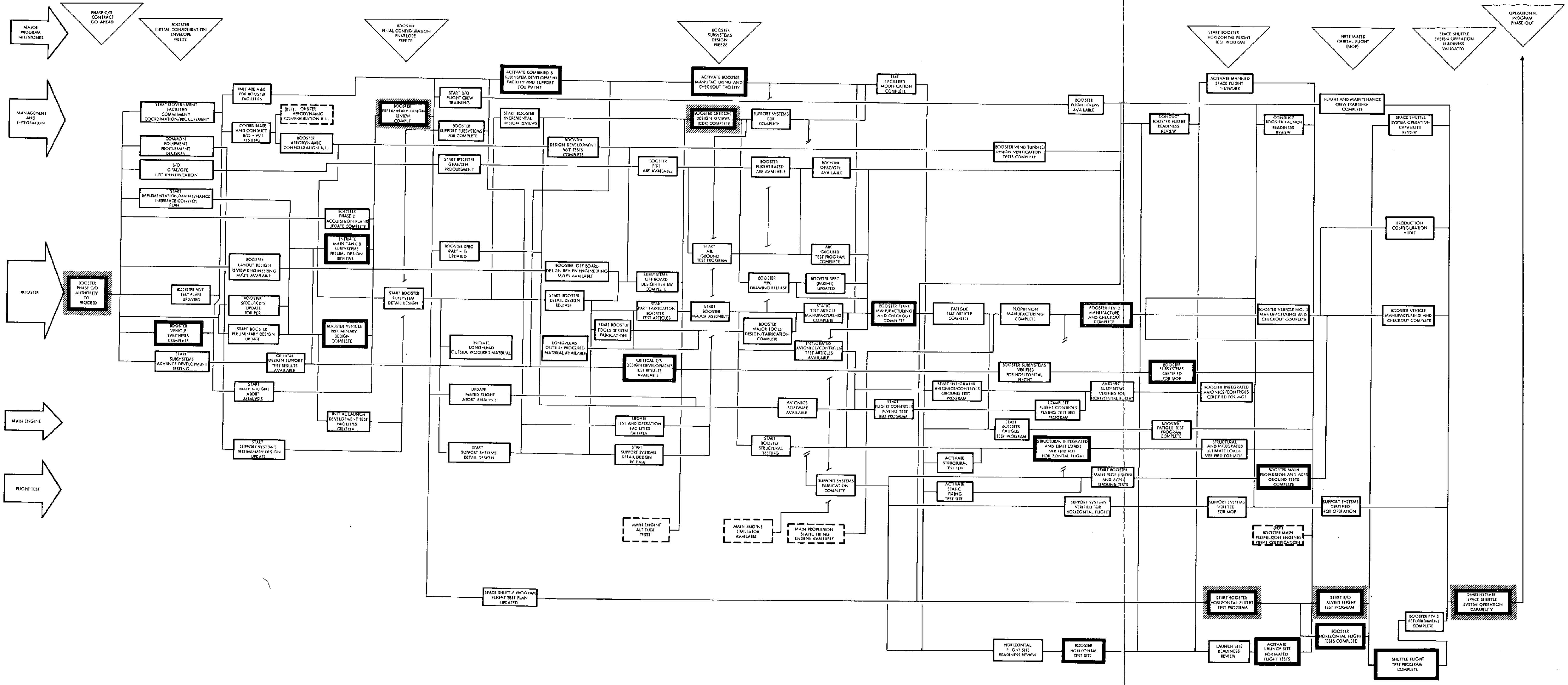


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Figure 4-1. Space Shuttle Booster Phase C/D Program Logic Network

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Additional design tasks to be initiated during this period include:

1. Abort analysis, upgrading the analysis initiated during Phase B to define in detail the impact upon the booster vehicle subsystem design and the avionics software.

2. Human factors analysis to initiate an in depth evaluation of man-machine interfaces, identifying and defining system and subsystem requirements and design solutions to provide a vehicle that integrates the crew, their habitation, and working conditions.

3. Preliminary design of the booster peculiar support equipment (SE) and booster-orbiter common SE.

4. Definition of the facility design criteria for test, manufacturing, and operations.

5. Updating and/or initiating fabrication of mockups.

6. Maintenance/support analysis to provide for adequate support planning.

The concluding event in the preliminary design effort is the review and the approval of the booster vehicle and its associated support equipment design through a series of preliminary design reviews. PDR's will be supported by an engineering data package consisting of design criteria documentation (Part I of the CEI Specification, Interface Criteria), preliminary design drawings, layouts, schematics, diagrams and functional descriptions, engineering analyses and test results, program development requirements, program activity schedules, and other data supporting the design solution presented at the review. In addition, mockups of the vehicle and complex support equipment will be available to support these reviews. At this time the updated Phase D acquisition plans will be presented to NASA for approval to proceed with the detail design and development of the booster system. The PDR review cycle starts with the booster vehicle and its subsystems. After completion of the vehicle PDR, support system equipment design can be further developed and PDR's conducted for each individual support equipment.

4.1.2 Detail Design

After completion of the PDR's and approval is given by NASA to proceed with the detail design, the Booster CEI Specification will be updated in accordance with the results of the PDR. Both detailed design of the booster vehicle and its support equipment can be initiated along with the preparation of the specifications to procure various booster system equipment. Concurrent with the detailed design effort, activities related to achieving successful development of the most cost effective booster system (i.e., reliability, safety, supportability, maintainability, risk assessment, producibility, quality assurance, commonality and standarization) will be continued from the preliminary design phase and intensified where it is known to be effective in minimizing cost and improving system/subsystem performance.

The vehicle and the support equipment PDR's will constitute agreement between NASA and the contractor concerning all system elements included in the booster system contract. Based on this concurrence, the contractor will update the Phase D acquisition plans, which form the basis for the Phase D development effort. Primary emphasis in updating the acquisition plans will be in detailed definition of all the development activities, including schedules, and an updated cost estimate to complete the contract.

The testing activity to support the design definition will be increased to support and develop the designs during this period. Testing will include breadboards, prototype components, subassemblies, and subsystems. These tests will cover structural integrity and functional and operational characteristics of the above type hardware assemblies. In addition, booster GFE procurement will be initiated to support the development test program for the propulsion subsystem. Throughout this period between the preliminary design review (PDR) and the critical design review (CDR) the wind tunnel test program will be continued, using updated design models. The test objective is to verify the design analyses and provide data to update various mathematical models.

As detailed design drawings are released, booster tooling design for the fabrication of the vehicle will be initiated and major structural components fabrication will be initiated to support the structural test program. Detailed plans for operational use of the system, such as training plans and logistic and maintenance plans, will be developed primarily during this period.

During this period, as each major element of the booster system detailed design is completed, CDR's will be held under NASA supervision. Incremental CDR's are necessary to maintain continuity in the design, test, and manufacturing effort. As each element concludes its CDR and NASA approves the design, procurement and fabrication will be initiated to support the development test program for both major ground and flight tests. Concurrent with fabrication and assembly of the flight vehicles and their support equipment, mod kits for flight test purposes will also be designed and fabricated. Training equipment, manuals, and handbooks will also be developed to support the flight training program.

The CDR's will be supported by a data package consisting of applicable CEI design requirements, design criteria documentation including Part II of the CEI specification, interface and environmental criteria, and design studies; and other documentation to support the objectives of the CDR as specified in the Program Management Plan. Models and hard mockups will be available to demonstrate the equipment where these are contractual items.

Upon completion of the CDR's, engineering activity will be oriented to supporting the manufacturing operations and the test program through design of equipment, definition of processes, and specifying procedures. Design improvements will be initiated whenever test data and manufacturing operations identify design deficiencies in various elements.

The supporting engineering activity for the various major test and the manufacturing programs is shown in the logic network. These include the manufacture and test of propulsion, avionics, structure, vehicle support, mechanical subsystems and support equipment in addition to the booster flight test vehicles.

4.1.3 Flight Readiness

Prior to initiating the booster vehicle flight test program, NASA will conduct the booster vehicle flight readiness review (FRR) to determine the vehicle readiness to begin the horizontal flight test program. To substantiate the airworthiness of the booster vehicle the FRR will be supported by a FRR report. This report includes:

1. Results of equipment checkout and test operations up to the date of the FRR.

2. Review of configuration status to the subsystem level identifying all interim systems, inactive systems, and systems of prequalification configuration; this includes certification that the end items are described by officially released engineering drawings and specifications.

3. Identification of waivers and deviations to specifications and basis for approval.

4. Status of all development, qualification, and reliability testing that constrains the flight mission.

5. Status of critical life component and life remaining.

6. Identification of shortages and open work items.

7. Summary readiness assessment and recommendations.

4.1.4 Flight Test

Horizontal flight tests will be conducted as part of the development contract. The pilots will be part of a combined NASA/contractor flight test team. The basic objectives of the subsonic horizontal flight test program are to verify the booster vehicle operational flight-worthiness for the cruise phase and for ferry operations; to substantiate the validity of design assumptions, calculations, and design support laboratory test results; and to verify the operational interfaces.

Prior to initiating the flight test program a site readiness review (SRR) will be conducted under the chairmanship of NASA. The SRR's purpose is to ensure that the test facility and the vehicle support equipment necessary for the flight test program are in conformance with the design and performance requirements. These reviews will be held for each flight test facility, both horizontal and vertical.

The second booster vehicle will support the first manned orbital space shuttle flight test. This flight and subsequent flights of the development program will be performed under the control of NASA with the contractor providing the technical support services.

4.1.5 Mated Orbital Flight (MOF) Test

The MOF test program will be initiated after sufficient confidence has been obtained from the overall ground test and horizontal flight test to assure a successful MOF test. Since these tests will be performed using the orbiter and the payload module simulator from the operational test site, they will not only verify the space shuttle air vehicle but will determine the adequacy of the operational test facility, its support equipment, and the turnaround maintenance facilities, equipment, and operational concept. In addition, all elements of flight mission support, including communications, tracking radars, mission control, and navigational aids, will be verified.

4.1.6 Operational Program Readiness

The operational program will be gradually phased in during the MOF test program. After completion of the final development test flight, the operational support equipment installation will be completed and a SRR performed to certify that the launch, maintenance and repair, and recovery facilities and support equipment conform to the design and performance requirements.

Prior to acceptance of the contract end item by NASA, a production configuration audit (PCA) will be performed on the first deliverable production system elements. PCA's will be supported by a data package to be reviewed at the CEI configuration inspection. Specific data requirements to support the PCA's are contained in the Program Management Plan.

4.2 DEVELOPMENT RESPONSIBILITIES

The overall Space Shuttle Program execution is under the direction of NASA. NASA is responsible for contracting for the booster design, development, fabrication, assembly and test effort; plus supporting the development with internal activites, including scientific, systems engineering, manufacturing engineering, test, quality and reliability assurance, and management efforts to assure successful performance and technical adequacy of the Space Shuttle Booster Program.

The contractor, under the direction of NASA, will be responsible for the design, development, fabrication, and installation of GFE; assembly; testing; and the flight test support of the space shuttle booster vehicle and its associated support equipment. In addition, the booster contractor will be responsive to NASA in discharging his contractual responsibility for this development and will coordinate his activity with NASA.

The contractor's design development task descriptions presented herein are organized in accordance with level 5 of the contract WBS, Figure 4-2. Other contractor responsibilities reflected on the WBS at level 4 only are summarized in this plan and are defined in detail in the appropriate Phase C/D acquisition plans.

The contractor's design development task descriptions contain two elements: (1) development requirements, and (2) test requirements. The performance and design requirements for the space shuttle booster are contained in the Space Shuttle System Specification and the Booster CEI Specification, Part I, both of which are incorporated herewith by reference.

In performing the design development of the booster vehicle and its associated support equipment, the contractor will accomplish the normal engineering design development of the hardware elements including:

1. Defining the detail design requirements and accomplishing the preliminary and final detail design of the booster vehicle and support equipment.

2. Performing trade studies, analyses, and development tests to define the optimum hardware configuration.

3. Providing the drawings and specifications for manufacturing/ fabrication, and assembly of the components/subsystems.

4. Defining the test requirements and objectives for the booster system/subsystems and its components and coordinating the test program to achieve the expected results.

5. Performing liaison and interfacing with the other space shuttle contractors to ensure the program objectives are being achieved.

6. Providing definition of suitable facilities for launch, recovery, operation, and maintenance of the booster.

7. Providing operational and support requirements for the booster.

The task descriptions contained herein are expansions of the above general category of design activity.

4.2.1 NASA Engineering Management

NASA will provide scientific, systems engineering, manufacturing engineering, test, quality and reliability assurance, and management efforts to assure successful performance and technical adequacy of the Space Shuttle Booster Program. This includes all actions necessary to ensure that the entire system is successfully designed, developed, produced, tested, delivered, and launched to carry out the specified missions on the scheduled data at the lowest practical costs. Specifically, NASA will:

1. Provide for facility acquisition and management.

2. Direct and review the contractor performance.

3. Chair formal PDR's, CDR's, and periodic progress reviews.

4. Provide contractor direction in design development.

5. Coordinate services amongst other NASA and government agencies for booster program.

6. Establish information systems and channels.

7. Provide coordination and communication services relative to flight operations.

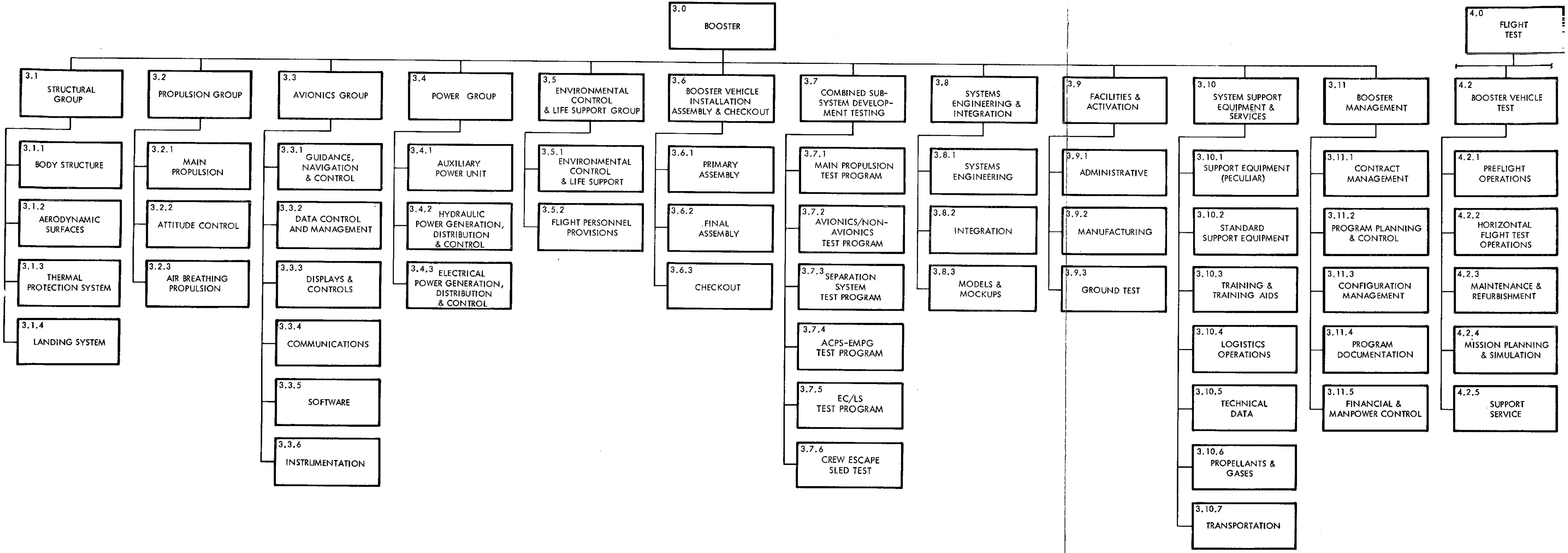

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Figure 4-2. Space Shuttle Booster System Contract WBS

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8. Assist in resolving technical interface problems between the orbiter, booster, main engines, facilities, and associated equipment.

9. Establish working environments with non-shuttle development functions in order to implement mutually agreed interfaces with these functions.

10. Arrange for timely provision of GFE to support development and qualification test programs.

11. Establish responsibilities, authorities and interfaces for design, development and test between foreign goverment participants and the booster contractor.

12. Ensure accuracy/currency of all interface documentation.

4.2.2 (WBS 3.11) Booster Engineering Management

The booster contractor management system is described in the Program Management Plan. This plan defines the booster contractor's methodology for planning and controlling the booster engineering and development program using the contract WBS as a common management framework.

The contractor management system will include a booster program management organization and tools necessary to fulfill the contract requirements, functional management and management tools necessary to achieve program and technical objectives, and a management information system that will integrate the program and functional management tools using the WBS as a common framework.

An extension of the Program Management Office will be the Booster Engineering Project Offices which direct, control, and monitor the design development effort within the engineering functional disciplines. It will participate in the formulation and fulfillment of program policies, directives and operating procedures, and will provide the technical data and documentation to management and NASA. In addition, it will serve as the primary interface with NASA on matters related to technical program interests and be responsible for integrating engineering activities with other functions.

The engineering activity will include the overall engineering program plans, subcontractor management, analysis and design, development, and testing of the booster system, flight plans, configuration control, technical documentation, and other technically related activities.

4.2.3 (WBS 3.8) Booster System Engineering and Integration

Contractor's system engineering and integration will include engineering and related functions necessary to ensure the design definition and development of a booster vehicle and its associated support systems which will satisfy the mission requirements in an economical and effective manner. This function includes system engineering, system integration, advance studies, and models and mockups.

(WBS 3.8.1) Booster System Engineering

This section describes the booster system engineering activities related to design, human factors, abort, and system technologies.

(WBS 3.8.1-1) Design. The contractor will conduct a system engineering design program in support of the design and development of the booster system hardware. The design effort will include system definition including requirements definition and mission/payload analysis and preliminary design, design integration, system optimization, interface compatibility, design reviews, technical risk assessment, technical performance measurement, and system engineering data.

1. System Requirements. Requirements allocated from the shuttle system specification and assigned to the booster system contractor will be analyzed and allocated for assignment to lower tier subsystem and component specifications. This process will give consideration to the design reference missions, interfacing shuttle system elements, baseline configuration, functional flows and timelines, subsystem definition, development facilities, and operational aspects. Requirements definition will be integrated with the maintenance, reliability, safety, operations, manufacturing, and quality engineering to ensure incorporation of their design considerations.

   In deriving requirements, the contractor will include in his analysis the environmental considerations. NASA will define the natural environments; however, the contractor will define the vehicle-induced environments by analysis for establishment of appropriate test requirements.

2. Mission/Payload Analysis. Support mission/payload analysis for the shuttle system by refining functional flows, time lines, and mission descriptions to assist in determining essential booster and ground system requirements. Mission characteristic parameters will be used to ascertain impact on requirements. Mission

planning data, human factors, and functional analysis will be used to establish crew tasks and flight procedures.

3. Preliminary Design. Based upon the Phase C/D shuttle system and booster system requirements, the contractor will re-evaluate the Phase B booster preliminary design performing design analysis and studies during the preliminary design phase to re-establish the best orbiter/booster size relationship and staging conditions and present a finalized preliminary design configuration for the PDR. In performing this task, the contractor will:

   a. Identify all system and orbiter requirements and coordinate them into the initial system syntheses in parallel with the orbiter contractor.

   b. After finalizing the synthesis, redefine the booster external configuration, major elements, internal arrangements, subsystems, geometry, mass properties and performance.

   c. Coordinate all activities with the orbiter contractor and NASA to optimize the booster configuration.

   d. Develop inboard profile drawings and general arrangement drawings to redefine the best component arrangement and provide the basis for booster balance calculations.

   e. Coordinate trade studies, system sensitivity analysis, interface definition, performance analysis, wind tunnel tests and other analysis and studies which impact the booster vehicle configuration.

   f. Definitize in cooperation with NASA and the orbiter contractor performance/staging point/payload within the overall system.

   g. Establish with the orbiter contractor commonality of computer performance programs to ensure rapid convergence on agreed design points.

   h. Coordinate between layouts and the mockup activites the booster system space allocations and clearances.

4. Design Integration. Contractor will implement and maintain a system of integrating the vehicle design and the vehicle to the ground system design. Design integration includes control of internal subsystem interfaces, vehicle-to-ground system interfaces, trade

study control, monitoring of design progress, and conducting progressive internal technical design reviews, crew/human engineering analysis, integrating engineering test requirements and monitoring of the test planning to assure that integration of the verification requirements is established in a logical and economical manner.

5. System Optimization. The contractor will perform studies and analyses to define a booster system that is the optimum design in terms of cost, schedule, and technology. In performing this task, the contractor will:

   a. Perform cost-effectiveness analysis to develop a low-cost, economical space transportation system for both development and operational aspects. Costs involved will be total program costs to ensure proper consideration of the impact of alternatives on both early year funding (development and production) as well as operations funding. Two types of studies will be performed. The first type will be investigation of alternatives meeting program, system, or subsystem requirements to identify the least cost solution. The second type of study will be concerned with the development of alternatives with different levels of effectiveness for determining the sensitivity to requirements.

   b. Perform design and performance sensitivity studies to define a booster system that is the least sensitive to changes in requirements.

   c. Perform system and subsystem growth studies to identify and define subsystems that can accept growth with a minimum of design perturbations.

   d. Perform commonality analysis to define equipment, subsystems, and/or subsystem elements which can be used in both the orbiter and booster systems.

6. Design Reviews. The contractor will be responsible for establishment of requirements, scheduling, and conduct of the preliminary design reviews (PDR), critical design reviews (CDR), flight readiness review (FRR), production configuration audit (PCA), and site readiness review (SRR). Necessary coordination will be effected with other associated contractors and NASA. PDR will be a series of design reviews conducted from the beginning of the contracted effort and will be considered completed when the support equipment

reviews have been completed. CDR will be a series of design reviews conducted from the beginning of the detailed design and will be considered completed when the design is essentially complete and NASA has approved. FRR and SRR will be formal NASA reviews and will be required to be accomplished prior to the first horizontal and vertical flights of the booster vehicle. PCA's will be formal NASA previews on the first deliverable production system elements.

7. Technical Risk Assessment. The contractor will perform technical risk assessment to identify potential major problems, and develop appropriate risk reduction plans to minimize the impact of technical uncertainties on mission performance and system development costs and schedules. Requirements description of the technical risk assessment is contained in Volume I of this plan.

8. Technical Performance Measurement. Contractor will identify critical performance parameters and values and accomplish the technical achievement planning necessary to provide an organized and timely means of assessing technical program progress toward achievement of design objectives. TPM planning details are contained in Volume I of this plan.

9. System Engineering Data. The contractor will identify the specific system engineering process and interfaces utilized on the program, and will provide the Government with the data resulting from the system engineering tasks and as specified in the data requirements. These data will include specifications; preliminary design review packages; critical design review packages; design review agendas and minutes; configuration inspection agenda and minutes; configuration inspection packages; specification and deviation documents, drawings, and lists; computer program documentation; technical studies and analysis reports; electromagnetic interference control plan; and manufacturing methods and processes procedures.

(WBS 3.8.1-2) Technologies. The contractor will perform the analyses and studies to establish the vehicle performance for the design reference and other missions, to define vehicle configuration, and to support the design and development of the booster vehicle. Technical disciplines included in the technologies are aerodynamics, flight mechanics, dynamics, and aerothermodynamics. The contractor's tasks will include the following booster vehicle analysis, in addition to the mated ascent considerations defined in Volume I of this plan:

1. Entry and Flyback Performance

   a. Determine nominal detail performance for the return mission, including entry, transition, cruise, landing, and ferry; optimize performance to minimize flyback range and fuel, using energy management techniques.

   b. Establish off-nominal performance effects, including effects of atmospheric variations, aerodynamic variations, staging conditions, vehicle loadings, etc.

   c. Determine performance corridors and capabilities that provide intact recovery from aborted missions.

   d. Establish flight envelopes attainable by maneuvering and installed propulsion.

2. Configuration Aerodynamic Analyses

   a. Define aerodynamic characteristics, in terms of force and moment coefficients, over the operational flight regimes, defined by Mach number and angle of attack. Vehicle characteristics will represent full-scale flight conditions, including effects of control surface deflections, manufacturing surface conditions, protuberances, and propulsion effects.

   b. Establish off-nominal aerodynamic characteristics, including changes due to aeroelasticity, manufacturing surface asymmetries, etc.

   c. Define influence of interference on aerodynamic characteristics including influence of proximity of orbiter on booster during mated and separating regimes and of the ground plane during landing and takeoff.

3. Stability and Control Analyses

   a. Determine stability and control specifications, in terms of bare airframe dynamic stability characteristics, over the operational flight regime.

   b. Define dynamic stability characteristics, in terms of rate and acceleration derivative coefficients, in all axes, over the operation range of Mach number and angle of attack.

c. Define trim and stability boundaries (envelopes) in terms of center-of-gravity location over the operational flight regime.

d. Determine maneuver envelope (acceleration increment per unit control surface deflection) over operational flight regime.

e. Define flying qualitities, where relevant, such as minimum control speed, nose gear unstick speed, and speed stability (flight path stability) in the subsonic aircraft mode.

f. Define ability of aerodynamic control system to manage off-nominal conditions such as center-of-gravity offsets and surface misalignments.

4. Aerodynamic Loads Analyses

a. Define steady pressure distributions over surfaces for representative flight conditions, including mated flight, entry, and subsonic flight (body, wing, tail, canard, etc.).

b. Define component, total and distributed airloads for representative flight conditions.

c. Determine interference incremental pressure and airload effects due to proximity of orbiter and orbiter engine plume during mated flight and separation and attitude control propulsion system (ACPS) actuation during entry.

d. Define airloads and hinge moments on aerodynamic control surfaces during maneuvering flight conditions and representative design loading conditions.

5. Aerothermodynamic Analyses

a. Define the external aerothermodynamic environment to which the booster will be exposed to predict structural and thermal protection system (TPS) temperature distributions for material solution and sizing, and to support vehicle trade studies. Aerothermodynamic environment will be defined as that resulting from the motion of the booster through the atmosphere from lift-off to landing as well as the imposed environments from the main propulsion engines, ACPS, orbiter plume, and the air-breathing engine system (ABES).

b. Define aerodynamic heating resulting from the motion of the booster through the atmosphere from launch through landing using an analytical design approach that includes aerodynamic heating prediction methods with uncertainty factors backed by experimental results from wind tunnel tests and 3-sigma mission and abort trajectories. Aerodynamic heating predictions requiring attention will include interference, separated and reattached flow, surface roughness, gap, and transitional and turbulent boundary layer.

c. Define the main engine exhaust gas heating to the booster base and adjoining surfaces during thrust build-up before lift-off, and during launch. Heating associated with recirculation of the main engine exhaust based into separation regions caused by launch angle of attack and by the presence of the orbiter on the booster upper surface will be defined.

d. Define the heating associated with the interaction of the plume from the ACPS with the booster flow field during the recovery trajectory as well as the plume heating of the area surrounding the nozzles. Downstream influence on heating as well as local influence on heating will be evaluated.

e. Define the orbiter plume impingement heating of the booster during separation for engine out and abort as well as normal separation.

f. Determine the heating of the booster wing and control surface by the air-breathing engine exhaust gas during cruise back to the landing site.

g. Present aerothermodynamic environmental system design requirements as a series of heat transfer rate versus time plots where the heat transfer rate is evaluated at the TPS and structural temperature for corresponding times.

6. Static and Dynamic Loads

a. Define for the total vehicle the vehicle static and dynamics loads, including flexibility effects, for vehicle response to transient excitations and steady state forces imposed during the space shuttle mission profile and service life. Conditions for the total vehicle will include transportation; ground handling and erection; prelaunch winds; misalignment and launch system tolerances; loads due to buffet and inflight winds and gusts; booster engine shutdown at staging; orbiter ignition including engine exhaust plume effect; separation system operation; and maneuver and gust loads during entry, transition, cruise, landing, and taxiing. All loads, static and dynamic, will be expressed in terms of probability of occurrence where possible, including trajectory and vehicle system dispersion, and natural and induced environment variations.

7. Mathematical Model. Develop mathematical models that adequately describe vehicle characteristics for use in POGO, dynamic loads and stability analysis, and structural analysis. Verify accuracy of the models by subscale and full scale vibration and static deflection tests. The mathematical models are to include bending, torsional, axial degrees of freedom and incorporate effects of propellant sloshing and hydroelastic effects. The models will include (but not be limited to) propellant tanks and propellant, TPS, aerodynamic surfaces, thrust structure, landing gear, actuators, interstage system, propellant feedlines, and the propulsion system (engine model to be supplied by NASA). Calculate vibration mode shapes and frequencies for the booster vehicle and the mated configuration (orbiter model to be supplied by NASA) and key subsystem or substructure elements as necessary for dynamic analysis.

8. Stress Analysis

   a. Perform detail stress, deflection, fatigue, and creep analysis of the structural components to establish structural sizes, deformations, failing modes, and stiffness coefficients. Trade studies will be performed to select optimum materials and structural concepts.

   b. Develop mathematical models that adequately describe the vehicle structure to solve for internal load distributions and deformations in highly redundant or complex structural components.

   c. Develop design allowables for the design material and structural elements in the expected operating environment.

9. Fracture Control Program. The contractor will develop a design approach and fracture control program to provide a structural subsystem which will withstand the expected operating loads, pressures, and environment throughout its service life without experiencing rupture or brittle fracture. For each major structural component the program will include:

a. Development of a service load and environment spectrum.

b. Safe-life analysis to avoid fatigue failures.

c. Trade studies to determine the optimum fail-safe or safe-life design concepts and structural materials.

d. Residual strength analysis of components which are designed fail-safe assuming preexisting defects or obvious partial failures.

e. Safe-life analysis of components, which are not practical to design fail-safe, assuming initial defects. Flaw growth characteristics will be established to develop design stress levels, safe inspection intervals, or maximum initial defects size for non-destructive inspection.

f. Development of proof test requirements and methods for structural components where proof tests are feasible.

g. Evaluation of non-destructive test (NDT) methods to provide a periodic assessment of the existence or degree of criticality of flaws.

10. Noise Prediction

a. Establish far field and near field noise generated by the clustered engines of the booster. Far field noise estimates will establish the acoustic environment for ground personnel and structures in the area of the launch pad, and also for communities at some distance from the immediate launch area. Near-field estimates will provide the acoustic environment for the flight vehicles, equipment, and crews, and will provide the basis for preparation of specifications related to launch noise.

b. Establish far field and near field noise generated by the ABES installation on the booster. Far field noise estimates will provide the acoustic environment for ground personnel in the vicinity of the booster and also for communities in the vicinity of the airport and underneath the take-off and approach flight paths. Near field estimates will provide the basis for preparation of specifications related to ABES noise.

c. Determine the fluctuating aerodynamic pressures associated with the turbulent boundary layer, oscillating shock-boundary layer interaction, interference effects between the mated vehicles, and base pressure fluctuations. Estimates shall be furnished for the crew compartment area, at positions on the vehicle where significant shocks are expected, at representative positions for the various TPS areas, and at the base of the vehicle.

d. Determine response of the total vehicle structural and shell modes to acoustic excitation at lift-off to verify, or specify, stiffness requirements to ensure that high stresses and instability are not encountered.

(WBS 3.8.1-3) Abort. The contractor will perform a comprehensive abort analysis to define the abort operations required to meet the Space Shuttle Program objective of intact abort. Intact abort is defined as the capability of the booster and orbiter to separate and continue flight to a safe landing where the orbiter will land with a full payload. In accomplishing this overall objective, the contractor will:

1. Define the abort requirements, specifying the nature of the abort action, the times in which the action should be accomplished, and the conditions under which the action should be accomplished.

2. Define the general abort procedures that will meet the abort requirements.

3. Perform detailed flight mechanics analyses of these abort procedures applicable during flight operations. Analyses will include detailed dynamic analyses accounting for overall vehicle dynamics, propellant dynamics, structural dynamics, and control system dynamics.

4. Prepare a detailed abort operations definition for all mission phases; include the requirements imposed on both flight- and ground-based hardware, the required personnel operations and associated timelines for both flight and ground personnel, and the definition of trajectories to be flown.

5. Define the requirements for any ground-based or flight hardware/software required to accomplish the selected abort procedures and operations.

6. Monitor the other engineering tasks to ensure that the abort-related hardware/software requirements are being accomplished.

7. Define the above capability of the system and identify any limitations on abort capability.

8. Identify the effect, if any, of design changes on the abort requirements and capability of the system.

9. Conduct tradeoffs between the cost of system/subsystem design changes to improve hazardous situations and the cost of increased abort capability.

10. Define the abort training requirements for the crew.

11. Define specific abort mission rules as applicable for each of the flight tests and operational flights.

12. Define the abort operations simulation to identify changes in hardware/software design or abort operations.

(WBS 3.8.1-4) Human Factors. The contractor will perform a comprehensive human factors study to ensure that the booster and ground system designs are within all the parameters of biomedical and psychosocial considerations. These include, but are not limited to, the principles and application related to the areas of human engineering, training, life support, environmental control, safety, habitability, hazards, etc. The contractor will comply with the requirements of the booster specification and the NASA control document in establishing these related performance features and product configuration.

The human factors analyses to be performed to establish design requirements and perform the design and development effor to satisfy the requirements are defined in Volume I of this plan.

(WBS 3.8.2) Integration

The integration function will include booster intrasystem and intersystem (external to the booster system development) interfaces. Intersystem interfaces will include maintaining relationships with other space shuttle contractors and also with NASA and other government agencies. Intrasystem interfaces will include the coordination activity within the booster system development including the many facets of the booster contractor organization within the engineering function.

Interface Compatibility. The contractor will establish means of controlling interfaces. Interfacing elements of the shuttle system with respect to the booster vehicle and ground system will be defined, integrated and documented as interface control documents (ICD's). These ICD's will include the functional, physical and operating procedural requirements common to two or more external elements of the program. Joint operating plans and interface control plans will be established to ensure compatibility of design with the control document and will include necessary NASA approval requirements.

Integration of System Requirements. Contractor will assure the conduct of an integrated effort to include the optimized compromises of all specialty efforts and the integration of these into the engineering requirements. These specialty efforts include the primary functions of quality control, reliability, maintainability, producibility, transportability, safety and logistics.

Mass Properties. A mass properties control program will be established during Phase C/D to ensure that booster weight and other mass properties constraints are not exceeded. This program will be conducted in a manner consistent with the low cost and risk goals of the space shuttle program and program requirements are defined in Volume I of this plan.

Product Assurance. Product assurance task requirements encompassing reliability, maintainability, quality assurance, and safety are defined in Volume I, Section 5 of this plan.

(WBS 3.8.3) Models and Mockups

The models and mockups will be provided by the contractor in support of the program requirements. These are discussed in the following paragraphs.

Models. Contractor will design and fabricate models for the wind tunnel test program which is conducted to establish and verify the aerodynamic configuration for both the booster and the crew escape system, booster structural and control loads and pressure distribution, static and dynamic stability and control, mated and separating booster characteristics, power effects, aeroelastic loads and flutter, and booster alone and mated aerothermodynamic characteristics. Models testing to be performed in Government facilities will include the appropriate speed, angle of attack and Reynolds number ranges to evaluate the booster mission requirements including launch, normal and abort separation, entry, transition, cruise and ferry, and landing. Specific models to be developed are:

1. Structural Dynamics Models. The contractor will design and fabricate wind tunnel models to obtain data for structural dynamics

analysis verification. The models will include those required for flutter, buffet, ground winds and aerodynamic noise.

2. Aerodynamic/Thermal Models. The contractor will design and fabricate aerodynamic and thermal wind tunnel models to be utilized in the acquisition of force, moment, pressure distribution and aerodynamic heating data.

Mockups (Full Scale). Contractor will design and fabricate mockups for demonstrating and identifying problem areas in the arrangement of subsystem installations. Specific mockups to be provided are:

1. Crew Compartment. The crew compartment mockup will show: seat locations and positions for all modes of flight; windshield arrangement for visibility for approach and landing; control and display consoles; personnel equipment stowage; and interior and cockpit illumination. The mockup will be suitable for demonstrating normal ingress and egress from both horizontal and vertical positions to simulate horizontal (aircraft type) and vertical (launch pad) positions. Emergency egress methods will be demonstrated in both horizontal and vertical modes. Flight simulation and functioning controls and displays will be included. The mockup will include provisions for demonstrating maintenance access and replacement of typical components.

2. Aft Fuselage. The aft fuselage mockup will consist of the aft body structure, engine thrust structure, main rocket engines, fuel feed lines, plumbing, etc., to show the complete main engine installation including the aft bulkhead of the main LH_2 tank. Main structural load paths such as frames, longerons, bulkheads, firewalls, spars, etc., will be included. Engine replacement will be demonstrated for at least one rocket engine.

3. Air-Breathing Engine Installation. The air-breathing engine installation will include engines, mounting, removal/replacement doors, entry heat shields, fairings, fuel tanks and lines, firewalls and access panels to show the air-breathing engine installation. It will demonstrate engine replacement for at least one engine.

4. Intertank Area. The area between the tanks will include the adjacent tank bulkheads, mounts, carry-through structure, fairings and actuators for the canard, interstage attachment structure, separation mechanism (working), propellant lines and vents, major structural memebers such as longerons, frames, bulkheads, etc., to show equipment installations within this area.

5. Avionics Compartment. The contractor will fabricate a full scale mockup of the avionics compartment with simulated avionics, simulated mounting provisions, and simulated cooling provisions to check the installation, accessibility and removal of the avionics. This may be included in the crew compartment mockup.

6. Landing Gear. The main and nose landing gear mockups will show the external details of the landing gear struts, retracting links and wheels and tires. The surrounding airframe structure will be duplicated to show installation and operation of the gear and gear doors. The complete operating system, including acutators, switches, wiring, plumbing, etc., will be duplicated.

7. Engineering, Test, Manufacturing and Assembly (ETMA) Mockup. A combination wood and metal mockup of the booster vehicle less the right hand wing for assisting the major design, test, and manufacturing functions to define and establish design, procedures, assembly sequence, accessibility, etc.

Test Articles

The contractor will perform a series of certification tests in order to demonstrate and certify the performance, integrity, conformance to design requirements, and confirm the engineering analysis of the booster vehicle, its subsystems and associated support equipment. The major test articles which the contractor will develop, not including the flight test vehicles, are:

1. Structure.

   a. Static load booster structure test article.

   b. Fatigue booster structure test article.

   c. Landing gear test article.

2. Propulsion.

   a. Main engine system cluster test article.

   b. ACPS test article.

   c. ABES ground test article.

d. ACPS and APU hydraulic and electrical power test article.

3. Avionics. Avionics subsystem integration laboratory (ASIL).

4. Flight Controls. Aerodynamic and TVC flight controls test article.

5. ECLSS. Crew cabin/ECLSS laboratory.

Detailed test requirements, test objectives and definition of the test articles are contained in Volume III of the Preliminary Test Plan.

4.2.4 (WBS 3.1) Structural Group

The contractor will perform the design and development of the structural subsystem in accordance with the applicable design requirements, including those derived from the technical analyses for WBS 3.8.1-2 given in Section 4.2.3. Major elements of the structural subsystem consist of the body structure, aerodynamic surfaces, thermal protection system, and landing systems.

(WBS 3.1.1 Body Structure)

The contractor will perform the detailed design of the following structural subsystem assemblies:

1. Body, including the crew compartment structure, forward skirt liquid oxygen tank, intertank structure, liquid hydrogen tank, and thrust structure.

2. Mating and separation, including the linkages and support structure.

Body. Design studies will be conducted on the body to support the detailed design of these major structural assemblies. These studies will include:

1. Analyses of the booster and booster/orbiter combination to determine the loads applied at the mating and separation system interfaces and the stiffness characteristics required.

2. Analyses of the main structural members to determine the design loads and to identify the critical fittings and members, which are required to be of fail-safe design.

3. Studies to establish internal pressure design requirements for occupied spaces and tanks.

4. Study of minimum weight arrangements for stiffening compartments and tanks for internal pressure conditions and material selection.

5. Study wing-to-body and canard-to-body structural interfaces to assure thermal compatibility

6. Trade studies to determine optimum crew compartment cabin wall thickness.

7. Design studies to determine most favorable crew compartment windshield glazing material, laminate arrangement, and seal.

8. Design studies to ascertain the arrangement of the access hatch.

Mating and Separation System. For the mating and separation system, the contractor will design and develop a system capable of safely separating the orbiter from the booster. The attachment design will consider all static and dynamic loading conditions arising from erection, ground winds, launch, boost phase flight, and orbiter separation. These considerations include distribution of linkage loads into the structural shell of the boost vehicle, separation system, and associated support structure; fail-safe design where practicable or assure safe life by the application of fracture control techniques; design of linkages and support structure to stiffness criteria determined from dynamic analysis of the booster and orbiter interactions; and automatic initiation of separation in both the booster and orbiter. Contractor studies and analyses will include:

1. Determine the separation system geometry and the location and configuration of the associated support structure. The attachments to the orbiter will be located at suitable hard points on the orbiter to minimize orbiter structural weight.

2. Tradeoff studies of support frame depth to determine the most economical arrangement for compliance with stiffness criteria.

3. Studies of alternative retaining and disconnect mechanisms to select a system with minimum complexity and high capability for verifying satisfactory operation.

4. Material selection based on total program cost effectiveness. The use of high modulus composites for stiffness critical members will be assessed.

5. Dynamic analysis and computer simulation studies to determine separation trajectories, clearances, rates, accelerations, plume impingement, aerodynamics and loads for various separation conditions. This will also include thrust vector control and attitude control of the propulsion system to ensure sufficient capability for safe separation considering performance degradation due to failures.

6. Analysis to evaluate separation capability considering sequencing logic, interface with the on-board computer, tolerances on electrical and mechanical timing of operating sequences and envelope of booster engine thrust decay, and orbiter engine thrust buildup characteristics.

7. FMECA to determine level of redundancy required.

8. The effect of local aerodynamic heating rates on the exposed linkage and the need for a faired housing.

9. Stress, load, and deflection studies analysis for static and operating conditions. Spring rates will be supplied for links, booster structure, and orbiter structure for the various loading angles and loading directions.

10. Evaluation of mechanical and pyrotechnic devices as interconnects between the orbiter and the booster.

Technologies. The contractor will perform the supporting technology analyses/studies and tests to define the booster structural subsystem. These investigations will determine the loads, aeroelastic and flight characteristics, stability, separation system parameters, acoustic effects, structural response, heat transfer parameters and other dynamic, aerodynamic, and thermodynamic characteristics. The body and mating and separation system analyses will be performed in conjunction with the total system analyses specified for WBS 3.8.1-2 given in Section 4.2.3.

1. Static and Dynamic Loads. Determine vehicle static and dynamic loads, including flexibility effects, for local subsystem response to transient excitations and steady state forces imposed during the space shuttle mission profile and service life. Typical subsystem items include air-breathing engine deployment, landing gear deployment, separation system loads. All static and dynamic loads will be expressed in terms of probability of occurrence where possible, including trajectory and vehicle system dispersions and natural and induced environment variations.

2. POGO. Conduct stability analysis of the coupled structure-fluid-propulsion system to establish parameters to suppress system instability. The analyses will account for elastic mode coupling of the structure, fluid, feedlines, engine characteristics, and active and/or passive suppression devices.

3. Separation. Conduct the analysis, tests, and trade studies to develop separation system parameters under normal and abort separation conditions. Account for interference aerodynamics, engine exhaust plume factors, thrust transients, system mechanical tolerances, and component dynamic and static properties. The selected design parameters are to maximize performance, repeatability, and reliability.

4. Vibration Environment. Determine the vibration environment for the crew area and for all areas of the vehicle where equipment will be installed. The crew area estimate is required to assure that vibration levels are compatible with the maintenance of crew efficiency. Prepare equipment vibration specifications from the area estimates of the vibration environment.

5. Noise Attenuation. Analyze and test the crew compartment to assure that internal noise levels are below specified levels. Develop design criteria for structural arrangement and insulating materials to provide adequate noise reduction.

6. Aerothermodynamic. Using the aerothermodynamic environment, structural temperature histories normal and tangent to the vehicle surface will be developed. These temperature histories and gradients will be used to select materials and material gages. Trade-off studies will be performed to control structural temperatures and temperature gradients by increasing material gages and by changing structural arrangements. The use of coatings to enhance and restrict radiant energy transfer will be investigated.

Test Requirements. Certification tests will be performed to evaluate design concepts, verify analytical techniques, determine failure modes, and demonstrate structural adequacy of the final design. Test requirements are:

1. Wind Tunnel. Scale model tests to determine vehicle response to ground winds and to verify adequacy of response suppression devices for assisting in defining the design criteria for vehicle structure and response suppression devices; buffet model test to determine vehicle loads due to transonic ascent and return flight; capture trajectory tests with simulated engine exhaust to determine interference aerodynamic characteristics and plume impingement forces during normal and abort separation.

2. Certification Tests. Material property tests to provide data for generation of allowables and characterization tests that will provide data on non-critical materials. Tests will define the mechanical, physical, corrosion, optical, thermal, thermal cycling, fatigue, fracture, boarding, flammability, etc., properties of the various materials used in the booster design.

   a. POGO, a pulse test of the propulsion system feed line during firing to define the dynamic characteristics of the feed line-engine system under operating conditions.

   b. Sub- and full-scale vibration and load deflection tests to provide the data base for verification of predicted vehicle dynamic characteristics or for modification and refinement of the analytical models.

   c. Vibration and acoustics tests to define the noise and vibration levels and to verify design and assure reliable operation of equipment and subsystems.

   d. Static, fatigue, and fail-safe tests of full-scale flight-quality hardware to demonstrate compliance with the strength, life deformation, and damage tolerance characteristics.

(WBS 3.1.2) Aerodynamic Surfaces

The contractor will perform the detailed design of the aerodynamic surfaces consisting of:

1. Wing, including the main lifting structure, aerodynamic control devices, and main landing gear attachment.

2. Canard, including the main structural assembly, interface pivot tube, and actuating mechanism.

3. Vertical stabilizer, including the main structural assembly and rudder.

Design Studies and Analyses. Studies will be conducted in the aerodynamic surfaces to support the detailed design of these major structural assemblies. These studies will include:

1. Analyses of loads, loads distribution, and stiffness characteristics to determine the structural members.

2. Venting analyses of wing box cavity, canard, and vertical stabilizer to ensure that boost phase pressure will not constitute a critical load condition for the cover material.

3. Study of minimum weight arrangement for stiffening the aerodynamic surfaces.

4. Analyses of the booster vehicle for lifting and control surface flutter for the typical mission profile. Define the vehicle parameters that will not permit flutter of the mated configuration during ascent and the booster alone for return and ferry missions. The margin on flutter velocity will be demonstrated.

5. Conduct static aeroelastic analysis including divergence, lift effectiveness, and control surface reversal and effectiveness studies to ensure adequate structural stiffness for stability.

6. Conduct panel flutter analysis to provide design criteria for TPS panels and other key structural surfaces to prevent destructive flutter during the entire mission profile.

Test Requirements. Certification tests will be performed to evaluate design concepts, verify analytical techniques, determine failure modes, and demonstrate structural adequacy of the final design. Test requirements are:

1. Wind Tunnel. Flutter scale model to determine unsteady aerodynamics representative of the booster vehicle along its mission profile and to establish flutter boundaries as a function of mission profile; model tests to define the structural and control loads, static and dynamic stability, and control; panel flutter subscale and full scale to establish design criteria that will not permit panel flutter.

2. Certification Tests. Material property tests to provide data as specified in Section 4.3.4 (WBS 3.1.1, Body Structure). Structural test to ensure structural adequacy of the aerodynamic surfaces and verify analysis. Static, fatigue, and fail-safe tests of full-scale flight-quality hardware to demonstrate compliance with the strength, life, deformation, and damage tolerance characteristics.

(WBS 3.1.3) Thermal Protection System

The contractor will perform detailed design development of a thermal protection system that will protect the primary structure from heating incident to system operation. Trade studies will be conducted to determine the extent of such protection and the system design characteristics, based upon a design life of 500 missions without refurbishment or replacement.

The system design will be capable of withstanding the peak design temperatures and design thermal gradients without failure through the design life. The integrity of the system will also be maintained through the design life when subject to the pertinent acoustical, vibratory, and flutter-inducing environments through the launch, ascent, recovery, flyback, and landing phases of the flight profile.

Design and Analyses. Contractor's study and analyses will provide for:

1. TPS design that is coordinated with the design of a purge and venting system to assure the elimination of explosive mixtures and prevent accumulation of ice in the cavities around the propellant tanks.

2. Skin cover design to minimize purge gas leakage and to prevent the ingress of hot gas during recovery.

3. Venting system arrangement to minimize the peak differential pressure on the TPS panels.

4. Panel design to withstand pressure resulting from the air load distribution history and the variation of internal pressure throughout the flight profile and, if applicable, reaction to overall mechanical loads resulting therefrom.

5. System stiffness criteria adequate to prevent interference between the TPS and the underlying primary structure.

6. Study for thermal expansion of the TPS relative to the primary structure, or alternately in a restrained design. Account will be taken of thermal stresses induced by the restraint in both the TPS and the primary structure. Under combined loading conditions, including thermal stress considerations, components of the system will not exceed the specified total cumulative creep deformation for the relevant load/temperature profile through the design life of the vehicle.

7. Corrosion protection in the applicable environments through the design life of the vehicle.

8. Insulation packaging to prevent moisture absorption and venting to acceptable pressure throughout the flight profile.

9. Penetrations through the thermal protection system, such as landing gear doors, requiring reusable seals to prevent hot gas ingress during recovery.

10. Heat shield to protect the primary structure and subsystems in the thrust compartment from heating due to engine plume radiation, backflow, and recovery airflow. Tradeoff studies will be performed to determine the best combination of body base heat shield and protection for engine mounted components.

11. Ease of replacement of TPS panels in the event of accidental damage. Large segments will be readily removable to facilitate inspection and repair of the underlying primary structure and subsystems and access panels required to meet maintenance requirements.

12. Using the aerothermodynamic environment to develop TPS temperature histories normal and tangent to the vehicle surface, and temperature gradients normal and tangent to the vehicle surface. Where required, insulation thicknesses will be determined to limit structural temperatures to the design value. Boundary layer leakage through gaps in the TPS during recovery will be evaluated to define the maximum allowable to prevent exceeding TPS material temperature limits in the gaps and to prevent heating of internal structure and components above design temperatures.

13. Tradeoff study to determine the allowable external surface roughness for TPS panel stiffening without imposing weight and cost penalties associated with increased temperatures. Another trade study required is to determine if a blanket of insulation or insulation packaging of each internal component provides the best solution in terms of cost, weight, accessibility to components, and fabrication.

14. Fatigue analyses of critical TPS structure under combined acoustic and thermal stresses using appropriate cumulative damage theories to provide assurance of adequate fatigue life of the TPS elements. It will be shown that the TPS design fatigue life equals or exceeds the required fatigue life. Panel response for use in fatigue analyses will be determined for representative locations of noise levels and types of structures.

Test Requirements. Tests will be performed to evaluate competitive design concepts, verify analytical techniques, identify failure modes, determine relative merits of TPS designs, and demonstrate the structural adequacy of the final design for the predicted load/temperature environment. Test requirements are:

1. Wind Tunnel. Establish and verify the aerothermodynamic design requirements for the booster vehicle alone and mated with the orbiter vehicle.

2. Certification Tests. Material property determination for temperature ranges and environment covering the complete mission profile. Specific development tests will be performed to verify analytical prediction techniques and to assist in the design of TPS structures with unusual design details. Test specimens will range from coupon size to full-scale sections.

   Structural element tests of TPS to verify static and cyclic loading, sonic fatigue resistance, and structural life.

   Static, fatigue, and fail-safe tests of full-scale flight quality hardware to demonstrate compliance with strength, life, deformation, thermal exposure, and damage tolerance requirements.

(WBS 3.1.4) Landing System

The contractor will perform the design development of a landing system for mission and ferry landing and ferry takeoff in accordance with the booster contract end item (CEI) specification. The landing system will consist of nose and main landing gear, positioning mechanisms, shock struts, tires, wheels, brakes, anti-skid, steering, actuators, locks, and other deceleration devices, if required.

The landing system flotation characteristics will be compatible with the landing fields identified by NASA. Studies will be conducted to determine cost and schedule impact for modifying the runways if flotation characteristics result in excessive weight and cost penalties to the vehicle. Flotation analysis will be in accordance with SEG-TR-67-52.

Design and Analysis. Design and analysis effort will include:

1. Minimizing the tire and brake weight by restricting the design life to be compatible with the number of space shuttle missions.

2. Defining an emergency backup system for brakes, steering, gear extension, and door operation. A trade study will be conducted to determine level of redundancy required including free-fall capability of the gear.

3. Providing for mooring and towing by the gear.

4. Incorporating maximum interchangeability of the components of the lefthand and righthand gear assemblies to reduce cost and spares inventory.

5. Defining a landing gear system capable of withstanding the temperature, pressure, and vibration conditions throughout the mission profile without requiring replacement of any components.

A study will be conducted evaluating landing load factor to gear weight versus vehicle weight. This will be done in conjunction with the taxi dynamic load analysis to ensure minimizing gear weight.

Test Requirements. Tests will be performed to evaluate design concept, verify analyses, identify failure modes, and demonstrate the design adequacy of the final design. Test requirements are:

Certification Tests. Structural static and dynamic tests to verify the analysis with respect to loads, fatigue, deflection, and shimmy.

Functional and performance tests to verify the steering system, brake, anti-skid control, retraction-extension of main and nose landing gear design requirements.

Proof pressure and leakage tests of shock struts, brakes, anti-skid control, steering, retraction and extension of main and nose landing gear to verify design requirements.

Static, dynamic, and fail-safe tests of full-scale flight quality hardware to demonstrate compliance with the design requirements.

4.2.5 (WBS 3.2) Propulsion Group

The contractor will perform the design and development of the propulsion subsystems for the booster in accordance with the technical and contractual specifications of the space shuttle system. The propulsion subsystem consists of the main propulsion system (MPS), air-breathing engine system (ABES), and the attitude control propulsion system (ACPS).

(WBS 3.2.1) Main Propulsion

The main propulsion system includes the main engines and thrust vector control (TVC) and provisions for main tank pressurization, propellant feed, propellant quantity gaging, and propellant loading and unloading. The rocket engines will be provided to the contractor as Government Furnished Equipment (GFE). The contractor will be responsible for engine/vehicle integration.

Design and Analyses. The contractor will perform system analyses to the level necessary to support subsystem selections, system design, to define system performance, and minimize development testing required. Documentation of analyses performed will include data on alternative approaches/selections considered. Justification/rationale for selection of all materials will be documented. Analyses required include but are not necessarily limited to:

1. Propellant Feed System. Diameter optimization, start/shutdown analysis, pressure losses, trapped propellant, vortexing.

2. Pressurization Systems. Pressure schedules, gas temperature histories, ullage temperature profiles, stratification analyses.

3. Propellant Conditioning Systems. System temperature and flow rates.

4. Propellant Gaging and Depletion System. Tanking accuracy analysis, residual propellants, fuel biasing.

5. Thermal Analyses. Engine heat shield, feed duct insulation, system chilldown.

6. POGO analysis.

7. Flight and Ground Test Data. Analyze ground and flight test data and compare with predictions.

8. Loads and stress analysis.

In addition to the system analysis, the contractor will define a system design that reflects the program objectives of low cost and reliable, maintainable, and safe operating for both the vehicle and its support equipment, Pursuant to the design development, NASA will provide engine contractor test data for review and analyses to provide early identification of integrated engine/vehicle system problem areas.

Test Requirements. Tests will be performed to support and verify design analyses and to demonstrate the equipment satisfies the design requirements. Test requirements are:

Certification Tests. Demonstrate design of anti-slosh and anti-vortex, propellant depletion, propellant preconditioning, and the mechanical and thermal properties of the propellant system to support the design development.

Demonstrate the integration of the MPS including POGO, start and stop thrust buildup, and decay using a static test program.

Demonstrate the MPS, including the tanks, propellant feed lines, and pressurization, and the engines will perform in accordance with the specification requirements.

(WBS 3.2.2) Attitude Control Propulsion System (ACPS)

The contractor will design and develop an ACPS for the booster vehicle in accordance with the booster specification and consistent with the commonality decision to provide reactive thrust to the booster during the period between orbiter separation and booster transition; and to furnish gaseous H_2 and O_2 to the booster auxiliary power units as required during prelaunch, inflight, and postflight phases. ACPS airborne subsystems to be supplied by the contractor will include cryogenic propellant storage, turbopump feed, propellant thermal conditioning, propellant distribution, engine, system controls, and instrumentation. Vehicle to ground support system interfaces for the ACPS, including propellant fill and drain, gas generator exhaust disposal, and system checkout and maintenance, will be defined to support the definition of ground equipment requirements.

Design and Analysis. Contractor's tasks will include definition of the ACPS design and perform system, subsystem, and component analyses to support design, development, and testing. Analyses will be closely integrated with the design and test effort to minimize program costs. Analyses to be performed include:

1. Performance analyses to identify, specify, and evaluate system, subsystem, and component performance levels and requirements during all phases and modes of operation, including aborts. Particular emphasis will be placed on transient and pulse mode operation of the system and its components.

2. Thermal analyses to evaluate and determine component thermal histories and define requirements for thermal protection and control; performance of propellant storage, conditioning, and distribution to maintain required pressures and temperatures; performance of propellant fill and drain system for both vertical and horizontal flights; and vehicle/ACPS interface thermal efforts.

3. Structural analyses, including static and dynamic, as required to support design and installation of system components.

4. System dynamics, control, and stability analyses to evaluate system and component response; establish requirements for and verify adequacy of system controls; evaluate and ensure system stability under all operating modes. Computer programs modeling the system and its components will be developed and utilized to support system and component design and ground and flight test programs.

5. Acoustic environmental effects analyses under prelaunch and flight conditions with specific emphasis on effects of main propulsion system operation.

6. Propellant acquisition and control analyses to identify requirements for zero or low g propellant acquisition devices, propellant slosh baffles, and propellant outflow control devices.

7. Engine and APU duty cycle analyses to identify component cyclic requirements, establish operational modes, and support propellant consumption analyses.

8. Failure mode and effects and hazard analyses to ensure maintenance of the fail operational/fail safe (FO/FS) requirements.

The development of the ACPS will require the need to interface with the other functions to ensure that the system meets its development objectives. These tasks will include:

1. Establish component, subsystem, and system instrumentation requirements, and sensor configuration for flight test and production vehicles.

2. Determine ACPS component, subsystem, and system electrical requirements for power supply, performance monitoring, and control. Coordinate and integrate requirements and designs with the vehicle avionics system.

3. Establish support equipment (SE) requirements for the system including interface and operational requirements for normal, abort, and emergency modes.

4. Determine maintenance, checkout, and operational requirements for the ACPS and its components. Prepare procedures and operating/maintenance instructions to support assembly, test, checkout, and flight operation of the ACPS.

Test Requirements. Tests will be performed to verify analyses, develop prototype designs, and verify adequacy of performance prior to proceeding with detail design and/or fabrication of production configuration components. Development testing at the component level will generally be required where a new design peculiar to the shuttle application is necessary and the component is not available as off-the-shelf hardware.

Certification Test. This test will evaluate and verify performance of components and subsystems when integrated in a systems operating environment. Cold flow and hot firing testing will be conducted using development hardware and will include facility and system checkout, design verification, mission simulation, component redundancy evaluation, APU integration, component iteration evaluation, and development of system operational and checkout concepts and procedures.

It will verify compliance of components and subsystems with design specifications. Where appropriate from considerations of cost, schedule, and test validity, component qualification may be conducted at the subsystem level. System tests will be performed to verify flight readiness of the integrated ACPS for all mission profiles and operating modes.

(WBS 3.2.3) Air-Breathing Propulsion System

The contractor will design and develop the ABES in accordance with the booster specification.

The ABES will consist of JP-fueled turbofan engines, air induction provision, anti-icing provisions, mounting provisions, engine starting provisions, fire protection systems, engine controls, engine fuel feed system, refuel/defuel system, tank vent system, and fuel quantity gaging provisions.

The engine will be a shuttle-qualified version of an existing engine configuration. Commonality with the orbiter air-breathing engine will be a design goal.

Design and Analysis. The contractor will perform system design and analysis necessary to support system design requirements:

1. Installed engine performance.
2. Air induction system analysis.
3. Engine starter system, ground and in flight.
4. Engine fuel feed, including engine start, suction feed, and engine shutdown.
5. Fuel tank vent system.
6. Refuel/defuel system performance.
7. Fuel quantity gaging system.
8. System environmental analysis, temperature, pressure, loads, acceleration, etc.
9. Inlet anti-icing system.
10. Fire protection system.
11. Engine mounting and deployment system structural analysis.
12. Fuel tank internal flow, surge control, and drain.
13. Flight and ground test data will be evaluated and compared with analytical predictions.

14. Vehicle ground test requirements including instrumentation requirements such as flow, temperature, etc.

15. Electrical and hydraulic power requirements.

Test Requirements. Ground and flight tests will be performed to assist and support the design development and to demonstrate the equipment satisfies the design requirements. Test requirements are:

> Certification Tests. Verify the deployment and in-flight start sequence under flight conditions, verify inlet performance, link system, anti-icing system, and establish engine cruise performance and operation.
>
> Check engine static performance and checkout engine systems, engine starting, anti-icing and fire protection, for safety of flight.
>
> Functionally check the complete air-breathing engine system prior to flight to check engine trim, starting system, ground cooling, and control rigging, fuel tank capacity, usable and unusable fuel, and expansion space, and calibrate the fuel quantity gaging system.
>
> Demonstrate the design adequacy over entire operating range, including inflight shutdowns and restarts, engine transients, engine-out drills, climb gradients, control effects, inlet performance, cruise performance documentation, nacelle and lube cooling, fuel tank and fuel system operation during climb and descent, siphoning characteristics of fuel tank, vent outlet icing, fuel impingement.
>
> Demonstrate the ABES meets the design and operations requirements and certify the system safe for flight.

4.2.6 (WBS 3.3) Avionics Subsystem

The contractor will define the avionics subsystem in accordance with the CEI specification. Elements of this subsystem are: guidance, navigation, and flight control (GN&C); communications; data and control management (DCM); displays and controls (D&C); software; and checkout/fault isolation (COFI).

The contractor will define subsystem instrumentation requirements and will be responsible for installation design for both flight qualification and operational usage. The definition, design, procurement and installation of sensors/transducers, which are an integral part of these subsystems, will be included.

(WBS 3.3.1) Guidance, Navigation and Flight Control System (GN&C)

The contractor will design and develop the GN&C system, which performs the guidance, navigation, and flight control functions in accordance with the booster specification. The following equipment are included: drive/pickoff electronics, rate sensors, aerodynamic surface servo amplifiers, air data sensors, ACPS valve drivers, thrust vector servo amplifiers, inertial measurement units, dedicated GN&C displays and controls, and computer algorithms unique to GN&C functions.

Design and Analyses. The contractor will perform preliminary design activities, and after completion of the GN&C preliminary design review (PDR) perform the detailed engineering design drawings, specifications, and analytical design data necessary to verify the validity of the GN&C subsystem design.

The contractor will perform the necessary analysis and simulations to develop the booster vehicle powered ascent, entry, and flyback control laws and techniques. The various operation modes for the flight mission will be defined. In addition, the contractor will:

1. Ascent Control. Develop mated vehicle ascent control laws and techniques considering thrust vector control (TVC). Include effects of launch drift, ground, and flight winds and gusts, sloshing and bending stability, separation, and system failure modes to arrive at total system requirements and weight, cost, performance penalties associated with TVC and blended control. Analyze ascent control systems to verify performance and stability in presence of known non-linearities, loads, and structural flexibilities.

   Perform analyses to verify that structural bending modes of the booster/orbiter combination do not cause control instabilities during mated portions of the mission. This analysis will include the effects of sloshing as developed by sloshing analyses and tests. Three dimensional mode analysis is required due to the asymmetric configuration.

   Perform analyses, as above, for the booster alone to verify that there are no structural feedbacks to cause control instability during flight of the unmated booster following abort or normal separation.

2. Entry Control. Develop booster control requirements for the period from separation to cruise utilizing ACPS and aerodynamic surfaces. Perform trade studies to determine flight maneuvers that minimize cost functions (e.g., minimization of fly-back fuel,

consideration of pilot tolerances, reduction of structural and heating penalties, etc.). Determine and specify the magnitude, duty cycle, etc., of control moment to be provided to effect the maneuver requirements. Include probable failure conditions. Evolve control laws and implementation for preferred entry control concept.

Determine and specify sensor requirements for performance of entry control. Evaluate probable sensor failure modes. Perform analyses of the attitude control propulsion system to verify system performance and stability during critical portions of the flight regime. The analytical model used will include known dynamics of the ACPS system, structural flexibility, and interaction with the air stream.

3. Flyback and Ferry Control. Develop control laws and system configuration for takeoff, cruise, and landing. Assess pilot handling qualities for approach and landing and verify required landing aids. Evaluate flare, decrab, and rollout maneuvers. Determine adequacy and requirements of stability augmentation during manual control. Establish control surface rate and deflection requirements during subsonic cruise, takeoff, and landing. Verify FCS stability margins with known nonlinearities, loads, and structural flexibilities.

4. Simulators. Verify flight control procedures for booster entry, transition, cruise and landing using a fixed-base, piloted simulator. Verify the adequacy of cockpit displays and controls. Evaluate handling qualities over the booster flight regime where manual flight operations are possible. Assess suitability of control concept for pilot operation in normal and in failure modes of flight operations. Evaluate static and dynamic loads, heat rate, heat loads, and control surface actuator loads during emergency (manual) flight operations. Determine spin susceptibility and identify any maneuvering restrictions required to avoid spin entry.

   Verify adequacy of the TVC, ACPS, and aerodynamic surfaces subsystem response characteristics including actuators, control valves, hydraulic system, and structural stiffness.

5. GN&C Requirements. Verify, or derive as may be required, GN&C system specifications for executing shuttle booster operations, including prelaunch, ascent, entry, cruise to landing site, and to satisfy the abort policies. Demonstrate by analysis or simulation of booster operations that the specifications are adequate for executing selected "worst case" missions; i.e., those near the system capability limits.

6. System Operations. Determine and describe operation sequences by crew and system hardware/software required to implement the automatic and manual system operations modes. Demonstrate that the GN&C system defined by the above specifications can execute all sequences of operations required to perform selected test missions (such as the most demanding ones).

Test Requirements. Ground laboratory and flight tests will be performed to verify analyses and adequacy of performance, develop prototype designs, and to demonstrate the equipment satisfies the design requirements. Test requirements are:

Certification Tests. Verify the GN&C system performance to perform the flight missions through the use of ground computers, demonstrate the compatibility with computer programs, and verify GN&C performance with other elements of the avionics subsystem.

Verify flight control procedures, handling qualities, and adequacy of cockpit displays and controls, using piloted simulators.

Control tests to verify performance and operational interfaces with TVC, aerodynamic control surfaces, ACPS, and the booster-orbiter and booster only structural bending modes and feedbacks.

Verify compliance of the components and the system with the design specifications.

(WBS 3.3.2) Data Control and Management and Instrumentation

The booster contractor will design and develop the DCM and checkout and fault isolation (COFI) system, which provides booster vehicle automated control and system/subsystem management for multimode multimission capability and vehicle readiness to perform its missions. The system will consist of the central processor unit (CPU), main memory, mass memory, sensors, and the data bus.

DCM Design and Analyses. The DCM subsystem will support COFI by implementing the performance monitoring and checkout functions and controlling the reconfiguration with failure isolation to a functional path. The ground checkout function will also be implemented.

The contractor will perform preliminary design activities which include initial DCM hardware/software requirements, equipment weights, volumes, locations, and interface data.

The contractor will also perform detailed design activities resulting in engineering drawings, specifications, and development of analytical design data necessary to verify the validity of the DCM subsystem design.

COFI Design and Analyses. The COFI will provide the following capabilities:

1. Determine subsystem performance or readiness to perform during prelaunch and flight phases.

2. Provide the capability to detect, verify and isolate faults to the functional path level for operational purposes and to the LRU level, where appropriate, for maintenance purposes.

3. Provide the capability to simulate dynamic operating environments to the degree necessary to support ground trouble-shooting and recertification of LRU's during maintenance and refurbishment periods.

4. Provide the capability for acquisition of data to be used for trend analysis during ground maintenance periods.

The COFI function will be integrated into the data management system to the maximum extent possible. The contractor's effort in this development will be to ensure that:

1. COFI will use the data management capability to sense, condition, and multiplex signals; process, compute, and compare data; sequence and generate commands; provide display interfaces and record results; interface with and be subject to an appropriate degree of crew control.

2. COFI will be implemented through specialized computer programs contained in the main and mass storage.

3. COFI program execution and configuration will be controlled by flight and ground crews through subroutine initiation using vehicle cockpit controls.

Test Requirements. Laboratory and development including ground and flight tests will be conducted to verify, demonstrate, and develop prototype designs. Test requirements are:

Certification Tests. Verify analyses, develop prototype designs, and verify adequacy of performance prior to proceeding with detail design and/or manufacture of production articles. Tests will include laboratory breadboards for design concept evaluation, mockups, and laboratory DCM and COFI computer simulation tests.

Verify that mating of the system will perform in accordance with the design requirements. These tests will include checkout, fault isolation, and redundancy management of the booster LRU's for COFI and for the DCM tests will include computer-data bus-mass memory, and tests utilizing acquisition, control, and test (ACT) units for control, checkout, fault isolation, and redundancy management of LRU's.

Verify COFI and DCM performance and operations through a flight test demonstration in conjunction with other elements of the avionics subsystem.

Verify compliance with contractor and NASA specifications.

(WBS 3.3.3) Controls and Displays System

The contractor will design and develop the displays and controls needed at the booster vehicle flight crew stations including multiformat CRT displays and supporting electronics, alphanumeric displays, caution and warning displays, manual flight controls, multifunction controls and buffer and sensors, and complete D&C panels including lighting. Internal and external lighting requirements and criteria are included.

Design and Analyses. The contractor will perform preliminary design activities to establish D&C subsystem component requirements, initial panel area allocations, panel lighting design, and initial caution and warning system criteria definition. D&C subsystem equipment, weights, volumes, equipment locations, and interface data will be provided.

The contractor will also perform detailed design activites resulting in detailed engineering design drawings, specifications, and analytical design data necessary to establish the validity of the D&C subsystem design.

Test Requirements. Tests will be performed to verify the analyses and design and to demonstrate system performance and operation. Test requirements are:

Certification Tests. Verify the analyses, develop prototype designs, and verify adequacy of performance prior to proceeding with the detail design and/or manufacture of the production configuration components. Tests will include functional simulation tests of the control and display, mockups, and laboratory breadboards.

Demonstrate the display and control concept and component evaluation with error participation and to demonstrate display and control interface with the DCM and other avionic subsystems.

Verify the compliance with contractor and NASA specifications.

(WBS 3.3.4) Communication System

The contractor will design and develop the booster vehicle communication subsystem, which performs the communications functions in accordance with the booster specification. System will consist of UHF transceiver antennas, antenna selectors, precision ranging equipment, processors, flight log recorder, VHF recovery beacon, audio center equipment, ATC transponders, and radar altimeters.

Design and Analyses. Contractor's design and development effort for the communication system will satisfy the following functional requirements:

1. Provide voice intercom between crew and ground personnel (during booster ground operations), and between crew and shuttle orbiter while mated.

2. Provide two-way duplex RF voice communications between booster and MSFN stations, and between booster and shuttle orbiter.

3. Provide two-way simplex voice communications between booster and air traffic control stations.

4. Provide down-link data capability between booster and NASA stations, and two-way data capability between booster and shuttle orbiter.

5. Transmit and receive ranging signals from ground transponders.

6. Provide identification signals to and from FAA navigational and air traffic control facilities.

7. Provide landing aids equipment capability to support automatic booster landings under Categories I and II conditions.

8. Provide crash type data and voice recording capability and radio beacon capability, which have a high probability of surviving atmospheric emergency conditions.

Preliminary design activities will include definition of all communication link power budgets, initial precision ranging system performance requirements, antenna requirements, and antenna window concept development, equipment weights, volumes, equipment locations, and interface data. Detailed design activities will include preparation of the engineering drawings, specifications, and analytical design data necessary to verify the validity of the communication system.

Test Requirements. Tests will be performed to verify the analyses and designs and demonstrate performance and operation. Test requirements are:

> Certification Tests. Verify the analyses, develop prototype designs, and verify adequacy of performance prior to proceeding with the detail design and/or manufacture of production configuration components. Test will include laboratory and flight evaluation tests of the precision ranging system to be developed for atmospheric and space navigation usage; integration tests of the precision ranging system with other functional booster systems during approach and landing phases, and with the IMU and guidance system for both space and atmospheric mission phases; integration tests for evaluation of control, measurement, checkout concepts of communication system components utilizing DCM computer and data bus concepts and antenna location and pattern.
>
> Verify the compliance with contractor and NASA specifications.

(WBS 3.3.5) Software

The contractor will develop and implement computer software for all elements of the avionics subsystem group including GN&C, communications, data control management, on-board checkout (failure prediction, caution, and warning) integrated displays and controls, power distribution and controls and shuttle program ground systems software and change control.

Design and Analyses. The contractor will provide design, development, production, and operational effort in support of breadboards, simulators, the avionics system integration laboratory (ASIL), and flight test. In performing these tasks, the contractor will:

1. Define and document an integrated program software development plan. The plan will be established at the outset of the program, defining the events and logical sequence in which all program software will be developed, produced, verified, and maintained.

2. Develop and document a program performance specification. This specification will reflect performance criteria in terms of operational, functional, and mathematical language. The specification will be used by both computer program design personnel and by personnel responsible for the procurement of the computer program. Upon acceptance, this document will become the baseline document for all subsequent software efforts.

3. Prepare and document a computer program design specification. This specification is written in programming terminology and translates the performance specification into technical, rather than functional terms. In addition, this document will establish the requirements for a higher order language (FGSS), compilers, emulators, translators, code generators, loaders, and assemblers. The compiler for the higher level language FGSS will be developed prior to program PDR, and utility software will be developed and tested concurrent with hardware development activities.

4. Develop and publish a computer subprogram design document. This document will contain the design details for each subprogram of the computer program. It will be generated from the computer program performance specification and the program design specification, and represents the further detailing of the computer program into individual tasks to be performed.

5. Establish and document a program data base. This document will provide the necessary technical description of the computer program data base. The data base is defined as the compilation of all permanent or semi-permanent data items contained in a computer program. The data base design document will identify the types and characteristics of all program data items, and describe the structural layout of the permanent or semi-permanent data that is necessary to carry out the function of the computer program.

6. Provide a computer program operator's manual. This manual will be written for the use of the computer operator and will present the instructions and reference information required for efficient operation of the computer program.

7. Provide a computer program test plan. This document will define the testing requirements for verification that the computer program fulfills the requirements of the computer program performance specification. It will define the detailed requirements for

each individual test and specifies the extent of testing and the criteria for acceptance of the program.

8. Provide computer program test procedures. This document will define the procedures for implementation of the testing requirements established in the computer program test plan. Information for each test regarding setup, operation, and evaluation of results will be presented.

Test Requirements. Tests will be performed to verify designs and analyses and to demonstrate system operation and performance. Certification test requirements are:

1. Simulation tests to debug and validate software modules before incorporation in operational hardware.

2. Avionics system integration laboratory will verify hardware to hardware to software compatibility on all avionics element.

3. Final integration tests to prove the compatibility of the avionics hardware and software with other vehicle subsystems.

4. Avionics flight test demonstration to generate confidence in the digital fly-by-wire system using a conventional aircraft with the necessary elements of the GN&C, DCM, displays and controls, communications, and software systems.

5. Horizontal flight test to verify proper operation of the avionics subsystem and demonstrate compatibility of the vehicle subsystem with ground facilities.

6. Vertical flight test to verify the proper operation of the avionics subsystem and avionics to the other vehicle subsystems and to demonstrate compatibility of the vehicle avionics and all other vehicle subsystems on both the booster and orbiter and between the booster and ground facilities.

4.2.7 (WBS 3.4) Power Group

The contractor will perform the power subsystem design and development for the booster in accordance with the booster specification. The subsystem group consists of the auxiliary power unit (APU), the hydraulic power and pneumatic system, and the electrical power system.

(WBS 3.4.1) Booster Auxiliary Power Unit (APU)

The contractor will provide an auxiliary power unit for the booster vehicle which satisfies and meets the design and performance requirements in the booster specification. The APU operates on gaseous hydrogen and oxygen supplied by the booster attitude control propulsion system. It includes a turbine supplied with H_2 and O_2 combustion products by a spark-ignited gas generator, oil lubricated gearbox, power takeoff pads for a hydraulic pump and an electrical generator, heat exchangers for hydraulic fluid and gearbox lubricating oil, a turbine exhaust recuperator, and required valving, sensors, and controls.

Design and Analysis. The contractor will provide the material and services to perform the design and development of the APU. As a part of this task the contractor will perform design studies and analyses to define a system that meets the program objectives. These studies and analyses will include:

1. Performance analyses to identify, specify, and evaluate system, subsystem, and component performance levels and requirements during all phases and modes of operation including ferry flight. APU load analyses will be performed to establish load profile and peak and average load levels.

2. Thermal analyses to evaluate and determine for all flight modes including ferry:

   a. Component thermal histories and thermal protection and control requirements for sea level and altitude operation, including insulation, active thermal control, and protective finishes resulting from environmental effects, entry heating effects, and system operation.

   b. Vehicle/APU interface thermal effects including, gas generator hot gas disposal, allowable component surface temperatures, and heat transfer between vehicle structure and system components.

   c. APU propellant temperature requirements, profile, and limitations.

   d. Design and operational criteria and performance of hydraulic fluid, lube oil, and turbine exhaust heat exchangers.

   e. APU gearbox thermal history.

3. Structural analyses (including static and dynamic) to support design and installation of system components.

4. System dynamics, control, and stability analyses to evaluate system and component response; establish requirements for and verify adequacy of system controls; and evaluate and ensure system stability under all operating modes.

5. Acoustic environmental effects analyses to define, under prelaunch and flight conditions, acoustic environmental effects on the APU, with special emphasis on effects of main propulsion system operation.

6. Failure mode and effects and hazards analyses to assure maintenance of the FO/FO/FS requirements. Justification for exceptions to the FO/FO/FS criteria must be provided. Chain reaction component failures within the system and failure effects of other booster systems (such as cryogenic leakage from some other system) will be considered and necessary protection implemented at an early phase of the design effort.

Test Requirements. Tests will be performed to verify designs and analyses and to demonstrate the system operation and performance. Test requirements are:

Certification Tests. Verify the analyses, assist in developing prototype design prior to proceeding with detail design and/or manufacture of production articles. Tests include developmental design concept evaluation of the gas generator, heat exchangers, recuperator and the interfacing with the hydraulic and electrical power sources to define design compatibility.

Demonstrate that the components and system satisfy the design requirements.

(WBS 3.4.2) Hydraulic Power Generation, Distribution and Control

Hydraulic Subsystem. The contractor will perform the design and development of a hydraulic system consisting of a fluid power generation, fluid transmission and distribution, flight control, and utility functions (landing gear, brakes, steering and engine deployment). In performing the design and development, the contractor will accomplish the studies and analyses to provide a system that optimizes cost while meeting all other program objectives. These studies and analyses will include:

1. Aerodynamic surface and thrust vector controls analysis to establish loads, rates, stiffness, frequency response, resolution, dury cycles, degradation after failure, monitoring, and display.

2. Trade studies to establish the number of hydraulic circuits/function, single or split surfaces, placement of servoactuators/surface for flight control.

3. Analysis to determine flight control actuator sizes based on loads or stiffness, servovalve flow rates, position loop gains, frequency response, failure detection thresholds, switching, transients, and damping. Perform failure modes and effects and hazards analyses.

4. Design requirements analysis to establish power levels and support equipment interfaces for the power generation element.

5. Establish for the power generation the number of hydraulic circuits, physical location, pressure level, and fluid selection.

6. Determine hydraulic power pump size, speed operating characteristics, flow demand versus time, reservoir sizes (thermal and exchange volumes), reservoir monitoring, filtration level and filter sizes, surge damping requirements. Conduct thermal analysis and determine heat exchanger requirements.

7. Determine for the fluid transmission and distribution element the tube sizes, allowable pressure drop, fluid velocity, insulation/isolation requirements, tubing material, and types of permanent and removable connections.

8. Establish for the landing gear and engine deployment loads, operating times and functional operation, steering loads and rates, braking distance, and torque. Determine the hydraulic versus pneumatic extension for landing gear and engine deployment.

Pneumatic Subsystem. The contractor will perform the design and development of the pneumatic subsystem, which provides the storage, conditioning, and distribution of all gases in flight on the vehicle and accounts for the supply of all inert gases required at launch and landing sites, and ensures their delivery at specified conditions and quantity.

To support the design and development effort, the contractor will perform the following studies and analysis:

1. Studies to determine the type and quantity of gases to be used, storage conditions, and types of conditioning equipment to be used.

2. Analysis to support system design for the purpose of minimizing testing.

3. Defining test requirements and interface requirements for ground support, special test, and launch facility equipment.

4. Provide failure modes and effects and hazard analyses and reliability analysis.

<u>Test Requirements</u>. Tests will be performed to verify designs and analyses and to demonstrate the operation and performance. Test requirements are:

> Certification Tests. Verify components and subsystems functional operation and performance. Tests will include breadboard testing of servoactuator to verify redundancy mechanization of control servos, permanent connections to verify strength and fatigue life, landing gear, and engine deployment subsystem to verify proper function and operation.
>
> Verify the functional characteristics of the flight control system, landing gear power and control, engine deployment.
>
> Verify subsystem operation and performance prior to the first horizontal flight, both pneumatic and hydraulic subsystems will be exercised and tests conducted.
>
> Verify the components are in compliance with contractor and NASA specifications.

(WBS 3.4.3) Electrical Power Generation, Distribution, and Control

<u>Power Generation, Distribution and Control Subsystem</u>. The booster contractor will design and develop the power generation, distribution, and control (PDC) subsystem. This subsystem is required to supply 115/200 vac, 400 Hz, and 28 vdc electrical power in the quantities and of the quality required by the booster electrical utilization subsystems and their components; regulate, convert, and control this power, and provide a distribution network to deliver the required power to the various component locations throughout

the vehicle. The subsystem will comprise the following major components: ac generators, generator control/regulator units (GCU's), power contactors, transformer-rectifiers, remote power controllers, distribution buses, batteries, circuit protective devices, and interconnecting harnesses.

The contractor will perform technical evaluations consisting of trade studies, analyses, and interface definitions in support of subsequent detail design decisions. Specifically these evaluations will result in equipment installation criteria, wire/harness routing criteria, power quality finalization, and cooling and access requirements.

The contractor will conduct, or be responsible for, the development and qualification test programs, laboratory subsystem simulation tests, applicable software evaluation tests, installation verification tests, and functional demonstration tests. The contractor will also provide engineering support for the manufacture of the PDC subsystem and its components.

Interior and Exterior Lighting. The contractor will design and develop lighting. Lighting is required to provide exterior illumination for night operations, illuminate crew compartments, and provide adequate lighting in equipment compartments where night time maintenance operations may be required. It includes the following major elements: anti-collision lights; wing, tail, and fuselage position lights; cabin lights; and equipment compartment lights. Display panel lighting is considered to be included in the controls and displays.

The contractor will perform technical evaluations consisting of trade studies, analyses, and interface definitions in support of subsequent detail design decisions. Specifically, these evaluations will result in: lighting equipment installation criteria, power requirements, preliminary test concepts, mock-up requirements, and data bus signal loading.

The contractor will also perform lighting detail design. The contractor will develop the analytical design and test data necessary to verify the validity of the lighting subsystem.

The contractor will conduct, or be responsible for the certification test programs, laboratory simulation tests, applicable software evaluation tests, installation verification tests, and functional demonstration tests. The contractor will also provide engineering support for the manufacture of the lighting and its components.

Electromagnetic Compatibility. The contractor will establish an electromagnetic control (EMC) program to govern all phases of the development program. This plan will be consistent with the requirements established by

NASA, and will be submitted to NASA. Requirements for the EMC program are defined in Volume I of this plan.

Test Requirements. Tests will be performed to verify designs and analyses and demonstrate operation and performance characteristics. Certification test requirements are:

1. To verify analyses, develop prototype designs, and verify adequacy of performance before proceeding with the detail design and/or manufacture of the production configuration elements. Tests will include laboratory breadboard for design concept evaluation, mock-ups, software evaluation, laboratory simulation tests, and functional demonstration tests.

2. To verify the performance of the system when two or more elements are mated. These tests will be performed with both dummy loads and with the other elements of the avionics subsystem.

3. To verify EMI compliance and to verify electromagnetic capability between related equipment.

4. To verify compliance with contractor and NASA specifications.

4.2.8 (WBS 3.5) Environmental Control/Life Support Group

The contractor will perform the ECLS subsystem design development in accordance with the booster CEI specification. Elements of this subsystem are the flight personnel provisions and the environmental control and life support system.

(WBS 3.5.1) Environmental Control and Life Support Systems

The contractor will design and develop the environmental control and life support system (ECLSS) to provide maintenance of a shirtsleeve environment with respect to temperature, pressure, and atmosphere composition, thermal control for equipment, pressure control of the crew compartment, and waste management commensurate with the booster mission.

The contractor will perform:

1. Studies and analysis to determine the elements of the ECLSS that best meet overall shuttle system goals within the schedule constraints.

2. System design functions to define an ECLSS that is simple, low cost, reliable and does not compromise crew habitability and safety.

(WBS 3.5.2) Flight Personnel Provisions

The contractor will perform the design and development of the crew system consisting of seats, restraints, flight controls, landing gear controls, engine throttles, consoles, and panels for displays and controls, hand holds and other aids for ingress and egress, survival kits, life vests, garments, and fire-extinguishing equipment in accordance with the CEI specification. Maximum commonality of equipment design and usage will be maintained with the orbiter system. The crew station will be designed for a crew of two 5 to 95 percentile crewmen.

Contractor design effort will include:

1. Studies to determine seat positioning requirements to accommodate boost, reentry, and horizontal flight conditions. Consideration will be given to minimize the effect of acceleration forces on the crewmen. NASA studies and tests on the physiological response to the $+G_Z$ acceleration loads will be utilized in determining seat configuration and positioning.

2. Design studies to develop a rapid means for emergency exit while on the pad and for emergency landings. Hand holds, steps, and rapid operating outward opening doors will be investigated in conjunction with ground aids for rapid egress. Design studies will be conducted to determine number and optimum location of emergency exits.

3. Studies to evaluate alternative in-flight crew escape devices.

Test Requirements

Tests will be performed to verify designs and analyses and to demonstrate the system operation and performance. Test requirements are:

Certification tests to generate information necessary to predict component and subsystem performance and to permit detail design definition; to provide confidence that components and subsystems will satisfactorily pass qualification tests; to do this to the extent necessary to verify that all interfaces are satisfactory and that interacting functions perform adequately and without degrading interference; and to verify that the ECLSS operates according to specification.

Verify that equipment has been designed to function properly in the specified environment.

4.2.9 (WBS 3.6) Booster Vehicle Installation, Assembly, and Checkout

The design engineering functions interface with the manufacturing engineering began during Phase B and will continue through Phase C/D. Initial interface with manufacturing engineering, which is responsible for converting booster design requirements into detailed manufacturing plans, was the producibility analysis of the product design to optimize the design for manufacture. The producibility analysis goal will be to ensure a proper balance between cost, schedule, and product design requirements. This analysis will be used to guide design toward a goal of providing hardware at least cost by defining the best manufacturing approach to producing the hardware while minimizing the potential manufacturing problems.

Other interfaces between the design and manufacturing functions will occur as the vehicle development proceeds through manufacturing mockups, checkout, and the development of support equipment for manufacturing sites.

The booster facility utilization and manufacturing requirements for Phase C/D are described in Volume II of the Space Shuttle Facility Utilization and Manufacturing Plan.

4.2.10 (WBS 3.7) Combined Subsystem Development Testing

The space shuttle booster development tests are described in Volume III of the Preliminary Test Plan. This plan provides the basis for evaluating cost, schedule, and confidence in the ability of the booster to meet performance requirements.

The booster test plan is based on a philosophy of minimum test hardware and maximum commonality of components with the orbiter. It provides an orderly progression of development and certification of the booster system hardware and software to the point of demonstration of space shuttle mission performance in mated flight test. The plan relates the tests to the test requirements delineated in the booster CEI specification and establishes test flows and schedules consistent with constraints identified in the development and test logics.

The engineering design and test functions are closely entwined since development tests are one method of assisting and verifying the design approach. Engineering will define not only the design requirements but also the test requirements and test objectives. Close coordination will be maintained between the two functions in defining the test descriptions, test durations, and the expected results.

Combined subsystem testing involves elements from two or more subsystems where the purpose of testing includes verification of interactions or interfaces of the subsystems. This differentiates from subsystem testing which is testing of complete subsystem or combination of elements of the subsystem. A subsystem is defined as level 5 of the WBS.

4.2.11 (WBS 3.9) Facilities and Activation

The requirements for facilities are described in the Facilities Utilization and Manufacturing Plan. This plan identifies all major new facilities and government owned facilities required for the development, test, manufacture, and operation phase of the Space Shuttle Booster Program. Facilities requirements are based on planning presented in the other acquisition plans and the utilization planning is directed toward providing optimum facility support of the Space Shuttle Booster Program objectives. A prime result of this effort is the planned use of a substantial number of existing government facilities.

Although the definition of the manufacturing facilities is the responsibility of the manufacturing engineering function, the definition of the test and operational facilities will be a joint effort of engineering design, test, logistics, and operations. Through this interchange of requirements, a basis for facility design will be developed to proceed with the test and operations facility design.

4.2.12 (WBS 3.10) System Support Equipment and Services

System support equipment and services include the requirements for support equipment, logistics management, training, personnel planning, technical support data, and propellants and gases. The support equipment requirements are described in this section of this plan. The other elements of the booster system support are described in the space shuttle phase C/D Logistics and Maintenance Plan. This plan defines logistics requirements and identifies support resources necessary to support development, test, and operation of the space shuttle, and further defines and illustrates the relationship that must exist between the logistics planning effort, maintainability, reliability, safety, and system design effort. Each logistic support element is described as related to its unique requirements from the design through operational phases. These requirements are determined by support analyses of vehicle and ground systems design, as well as mission and ground operations.

The design engineering function and the logistics and maintenance function have maintained close interface since the start of the Phase B definition study. Maintainability criteria for booster system design were established by the logistics function as well as participation in all the design trade studies to assess the maintenance and logistics impact upon the design. For Phase C, the logistics and maintenance effort will be directed primarily toward the expansion of the Phase B logistics support requirements and detailed analysis, definition, and development of the Phase C system requirements, plans, schedules, resources, and procedures. Activities will include vehicle design analysis from which each logistic support element will be analyzed, defined, programmed, scheduled, and developed into an integrated logistic support program. Support requirement analyses will be conducted to define the resources, planning and support requirements for the development, test, and operational phases for the vehicle and its support equipment. Maintainability analyses will provide the "design to" aspects for vehicle and support equipment maintenance. Phase D effort will provide the support systems and personnel and their skills and services to maintain, control, manage, and assist in the development, test, and operations of the shuttle program vehicles, support equipment and facilities.

(WBS 3.10.1) Support Equipment

The contractor will accomplish engineering design and development of the support equipment required for the booster and the mated booster/orbiter vehicles throughout all phases of the shuttle system program. Booster support equipment will include that which is common to the orbiter program. The booster contractor will integrate the orbiter-peculiar and payload-peculiar support equipment into the shuttle system program equipment.

Program support equipment requirements will be reviewed in terms of vendor needs, manufacturing and assembly needs, acceptance checkout needs and horizontal flight test needs in addition to the operational program. This review will assure that support equipment costs will be minimized by proper commonality of design, allocation of quantities, and scheduling of units.

Support equipment includes the items necessary for launch, handling, checkout, transportation, service, training, and software. The type of support equipment and the design requirements for such equipment will be determined from analysis of the requirements for the shuttle system airborne vehicles, their maintenance requirements, and facilities and interfacing equipment. The special needs of the test program will also be considered. Table 4-1 categorizes the types of support equipment necessary to be considered in order to support the six functional areas.

The contractor will perform the following tasks for each one of the support equipment categories (except as stated otherwise):

1. Determine detailed design requirements based on analysis of the specification requirements, airborne subsystem detailed design requirements, interfacing equipment, facilities design details,

Table 4-1. Types of Support Equipment

	Launch	Handling	Checkout	Transportation	Training	Service
Booster peculiar	x	x	x	x	x	x
Orbiter peculiar	*	*	*			*
Common	x	x	x	x	x	x
Payload peculiar	*	*	*			*
Mated shuttle system combination	x	x	x	x	x	x
*Integration only						

and maintenance requirements to identify support equipment and its design requirements.

2. Review the detailed design requirements for orbiter support equipment as they are determined by the orbiter contractor to determine which items should become common with booster support equipment.

3. Conduct design studies to establish detailed design approaches and solutions that meet the requirements of performance, safety, reliability, producibility, quality verification, maintainability, cost, and schedule. Solutions will consider making maximum use of existing surplus equipment, existing designs, commercial standard equipment, etc., to produce the lowest cost support equipment design with adequate performance.

4. Prepare for and participate in preliminary design reviews (PDR) and critical design reviews (CDR) with NASA, the Air Force, and associate contractors.

5. Perform the detailed support equipment design including preparation of layouts, block diagrams, schematics, and production drawings and specifications.

6. Determine development test requirements for the support equipment.

7. Provide technical coordination with NASA, the Air Force, and associate contractors.

8. Provide technical assistance to material procurement, subcontractors and manufacturing through acceptance of CEI first articles.

9. Provide technical data, manuals, test procedures, acceptance criteria, etc.

10. Provide technical assistance for installation and checkout or for demonstration of support equipment CEI first articles.

11. Prepare and maintain the software necessary to program the function and operation of programmable elements of the support equipment subsystems. The software will include, but not be limited to: ground computer programs for checkout, data reduction and processing, mission planning, flight operations, maintenance management, management information and control, simulation, and training. Specialized software required to configure, program, operate, and maintain other ground equipment items will also be provided. The contractor will also develop and implement an integrated data system for preparation and control of support equipment subsystem software and software related data.

12. Identify the software required to meet the requirements of the support equipment subsystem specifications, and present the purpose, application, and design approach at the support equipment subsystem PDR for each element of software. The contractor will consider the possibility of utilizing high level programming languages and of sharing common programs with the vehicle.

To accomplish objectives of the software development, the contractor will perform the following tasks:

1. Determine detail programming requirements and criteria, based on analysis of the requirement specifications, equipment design details, etc.

2. Conduct design studies to establish detail programming and coding approaches and solutions, and to meet the requirements for safety, security, and operability. Trade studies involving hardware, program, and personnel capabilities will be conducted to assure optimum solutions.

3. Perform the actual coding of the programs. Complete documentation of the programs will be prepared.

4. Maintain the programs and program documentation through the flight operations phase.

4.3 CERTIFICATION REQUIREMENTS

A certification program will be required in the engineering and development of the space shuttle system. This program will be comprised of development tests, qualification tests, acceptance tests, flight tests, facilities, and support equipment verification. The detailed requirements contained in the preliminary test plan are summarized in Volume I of this plan.

5.0 GENERAL ENGINEERING AND DESIGN REQUIREMENTS

The general engineering and design requirements include these elements of engineering that are necessary for a reliable, maintainable, safe, producible, transportable, booster system, and result in quality products. In addition, the basic engineering processes and design verification that identify the continuous activities necessary to support the engineering development effort constitute another element of the general engineering requirements. The requirements for the forementioned activities are defined in Volume I, Section 5 of this plan.

Specifically, Section 5 of Volume I describes the task requirements for:

1. System design considerations, including
    a. Reliability.
    b. System safety.
    c. Maintainability.
    d. Electromagnetic compatibility.
    e. Standardization.
    f. Human factors.
    g. Producibility.
    h. Transportability.
2. Engineering processes to support the engineering and development of both the booster and orbiter systems. These include:
    a. Technical program planning.
    b. Program Work Breakdown Structures.
    c. Technical problem solving.
    d. Technical study control.

e. Specification preparation and maintenance.

f. Drawing preparation and maintenance.

g. Change planning and processing.

h. Engineering release.

i. Interface control.

j. Weight, volume, and mass properties control.

k. Control of environmental criteria.

l. Material properties analysis and material use control.

m. Technical performance measurement.

6.0 POTENTIAL TECHNICAL PROBLEMS

The purpose of this section is to provide descriptions of the booster system potential technical problems and the alternatives planned to minimize their impact. Specific areas where technology development should be conducted in support of the booster system design and development phases are the TPS, the main propulsion engine feed system instability of POGO, mating and separation system, the transonic flight characteristics, the avionics subsystem, and the cryogenic reusable insulation.

6.1 THERMAL PROTECTION SYSTEM

6.1.1 Problem Statement

The TPS for the booster vehicle presents potential problems because the capability for reuse is not currently state of the art. The problem is further complicated by difficulty in making accurate thermal predictions for the complex flow field to be encountered during ascent and entry.

6.1.2 Technical Approach

Three candidate concepts are available, together with an interim approach should unforeseen development problems arise. A metallic reardiative TPS, a reusable external insulation, and a heat sink structure are the candidate concepts for the booster; the interim approach is to employ ablators.

In the metallic reradiative TPS concept a separate shell structure encloses and is attached to the primary body structure by use of suitable frames. No insulation is required except in the crew compartment area. Potential problems with the concept include prediction of surface temperature and TPS structural life and sealing of slip joints required to accommodate differential expansion and around local penetrations such as landing gear doors.

In the reusable insulation concept a nonmetallic thermal insulation material forms the outer surface of the vehicle. This approach affords the potential for forgiveness of unanticipated overheating and lower weight than the metallic reradiative system. Potential problems identified to date include the limited capability of the material to accept strain, its damage vulnerability due to inherent lack of toughness, and the need to develop a coating to prevent moisture absorption.

The third candidate booster concept, heat sink, employs body shells of sufficient thickness to afford sufficient thermal capacity to absorb the total heat load without exceeding the temperature limits of aluminum. This approach offers extreme simplicity in design, but is the most sensitive to variations in prediced heating rates. System weight increases too rapidly to be efficient above staging velocities of 8500 fps.

The baseline system selected is the metallic reradiative concept. Should material development indicate delay in first orbital flight a backup design will be available for implementation with minimum effort.

6.2 MAIN PROPULSION ENGINE FEED SYSTEM INSTABILITY (POGO)

6.2.1 Problem Statement

Characteristic pulsations in the main engine feed system, causing instability, have been experienced on previous vehicle systems. They are expected to be an area of conern for the booster vehicle. In addition to oscillatory pulsations affecting the vehicle structure-propulsion system, POGO-induced loads may be experienced at the booster-orbiter interface, causing additional problems due to the asymmetrical configuration of the mated vehicles. There may be significant coupling between lateral and longitudinal structural modes.

6.2.2 Technical Approach

The current plan is to utilize mathematical models coupled with test supplementation and basic research and development of POGO suppression techniques and devices. A stability analysis will be performed using the mathematical models to determine stability margins for various structural damping factors. These data will be provided through model and full-scale tests. A test approach would be pulsing the system during the main engine cluster firing and recording the accelerations and pressures at points along the tank-engine feedline to determine gain and phase relationship of the system under operating conditions. Suppression concepts employing accumulators, damping devices, thrust stabilization, and pressure control will provide developmental data required to suppress POGO.

6.3 ORBITER MATING AND SEPARATION

6.3.1 Problem Statement

The staging associated with parallel stage vehicles in environment from high to low dynamic pressures requires a complete knowledge of the forces on the individual components and the interaction of each on the other during normal separation and abort conditions. The separation must be without physical contact of the two vehicles and it also must be such that effects of the orbiter plume are predictable on the separating booster and the booster can recover satisfactorily from the separating maneuver and achieve a trim flight condition. The complexity of the shock-flow interactions dictates an experimental approach to the verification of satisfactory separation characteristics.

6.3.2 Technical Approach

The aerodynamic stability of the booster and orbiter elements during the separation sequence will be obtained from wind tunnel models of the typical space shuttle launch configurations. Model tests including abort staging, separation with plume, separation pressure distribution, and dynamic stability will be made to obtain static and dynamic load and flow conditions of the separating configurations under varying dynamic pressure conditions. The orbiter rocket exhaust plume will be simulated using high-pressure. Model motions during tests will be representative of actual motion during separation. In addition a mathematical model which simulates the actual separation event has been developed and used during the Phase B study to perform parametric and sensitivity studies. This model is verified using test data obtained from the wind tunnel test program and the ground test program, including structural, dynamic, and functional tests of components, assemblies, subsystems, and the full scale vehicle.

6.4 TRANSONIC FLIGHT CHARACTERISTICS

6.4.1 Problem Statement

The critical flutter, buffet, and loads conditions are expected to occur transonically during boost and entry flight. The unsteady aerodynamic forces are extremely complex in the transonic speed regime, especially due to the aerodynamic and shock interference between the mated vehicles during ascent. These fluctuating pressures and loads may cause structural fatigue failures, or can be the cause of significantly increasing the structural weight of the vehicle. It is therefore necessary to detect potential flutter and buffet instabilities early in the design so that the lightest possible fix can be employed.

6.4.2 Technical Approach

Wind tunnel tests will be conducted to determine fluctuating pressure distributions on the booster and the booster-orbiter mated configurations in the Mach number range from 0.6 to 1.4. In order to resolve the buffet problem area, the pressures will be converted to power spectral density

(PSD) form as a function of frequency. The vehicle transfer functions relating desired response functions to forcing frequency will be determined analytically. Input PSD will be combined with vehicle transfer functions to determine output PSD. Using standard techniques, the fatigue damage is calculated from the output PSD and the amount of time the vehicle will encounter this environment during its lifetime. Flutter resolution will be accomplished through the use of transonic flutter models to which the experimental wind tunnel results will be compared. Theoretical results will be obtained using kernel function, doublet-lattice, Mach box, and quasi-steady aerodynamic theories. These results will define the vehicle parameters that will not permit flutter of the mated configuration during ascent and the booster alone for return. Included in this analysis will be the definition of flutter velocity margin, divergence, lift effectiveness, control surface reversal, and structural stiffness requirements for stability. The flutter models will be verified by scale model wind tunnel tests and sub-scale and full-scale panel flutter wind tunnel tests. The scale model tests will determine the unsteady aerodynamics representative of the space shuttle along its mission profile.

6.5 INTEGRATED AVIONIC SUBSYSTEM

6.5.1 Problem Statement

The concept of controlling all electrical and electromechanical subsystems on the vehicle by a central computer through a main data bus and uniform data bus interface units is unique. It also presents a large software development task. The interface units or acquisition, control, and test (ACT) units allow acquisition of data, control, and tests including checkout and fault isolation through the main computer. While all the elements of the avionics and the interfacing subsystems present very little technology advancement, the integration and operation of the total system through the computer and its software does present a potential area of concern, especially in relation to the development schedule.

6.5.2 Technical Approach

Early conceptual design of the data bus system and ACT units has been initiated through NASA technology contracts. Achievement of performance requirements will be assured through parallel development efforts including performance verification through analytical simulation and breadboard testing. The development of the software depends on an early definition of the hardware baseline. To minimize this area of concern, a strong development plan giving high priority to the software design development will be implemented.

6.6 REUSABLE CRYOGENIC PROPELLANT TANK AND DUCT INSULATION

6.6.1 Problem Statement

Lightweight reusable cryogenic insulation for LH_2 tankage or propellant lines has yet to be developed that will withstand the mechanical and thermal environment associated with the life criteria of the space shuttle. Candidate insulation systems, presently being evaluated by several aerospace companies, must be compared before a final choice can be made.

6.6.2 Technical Approach

Baseline cryogenic propellant tank insulation is an internal insulation system utilizing a gas-layer concept that employs a unique foam (polyphenylene oxide). This development includes a coordinated analysis, design, and testing of a subscale insulated tankage system. The alternate design approach considered in the event of development problems is the external helium or nitrogen purged quartz fiber blankets.

For the cryogenic propellant duct insulation, the recommended approach is to conduct analysis on two types of promising, reusable insulation systems. These are (1) the rigid vacuum jacket propellant line with internal multilayered super-insulation, and (2) the external bonded sealed foam insulation.

7.0 SCHEDULES

The space shuttle booster schedule for Phase C/D is presented in Figure 7-1. It presents the program milestones to which the schedule of activity for each WBS element is keyed. Within each WBS element are listed three or four functional disciplines: engineering, material procurement, fabrication and assembly, and testing. These functions are listed to show the interaction and the reliance of the development program upon each discipline to have a well-coordinated schedule. This schedule presents the activities and events for the contract WBS elements comprising NASA level 4. Additional detailed schedule information to NASA level 5 elements and the interaction of the schedule activities and events are presented in the Cost and Schedule Estimates Plan.

7-3, 7-4 A

SPACE SHUTTLE BOOSTER - SUMMARY MASTER SCHEDULE

FINAL PHASE B BASELINE - 360 DAY SUBMITTAL

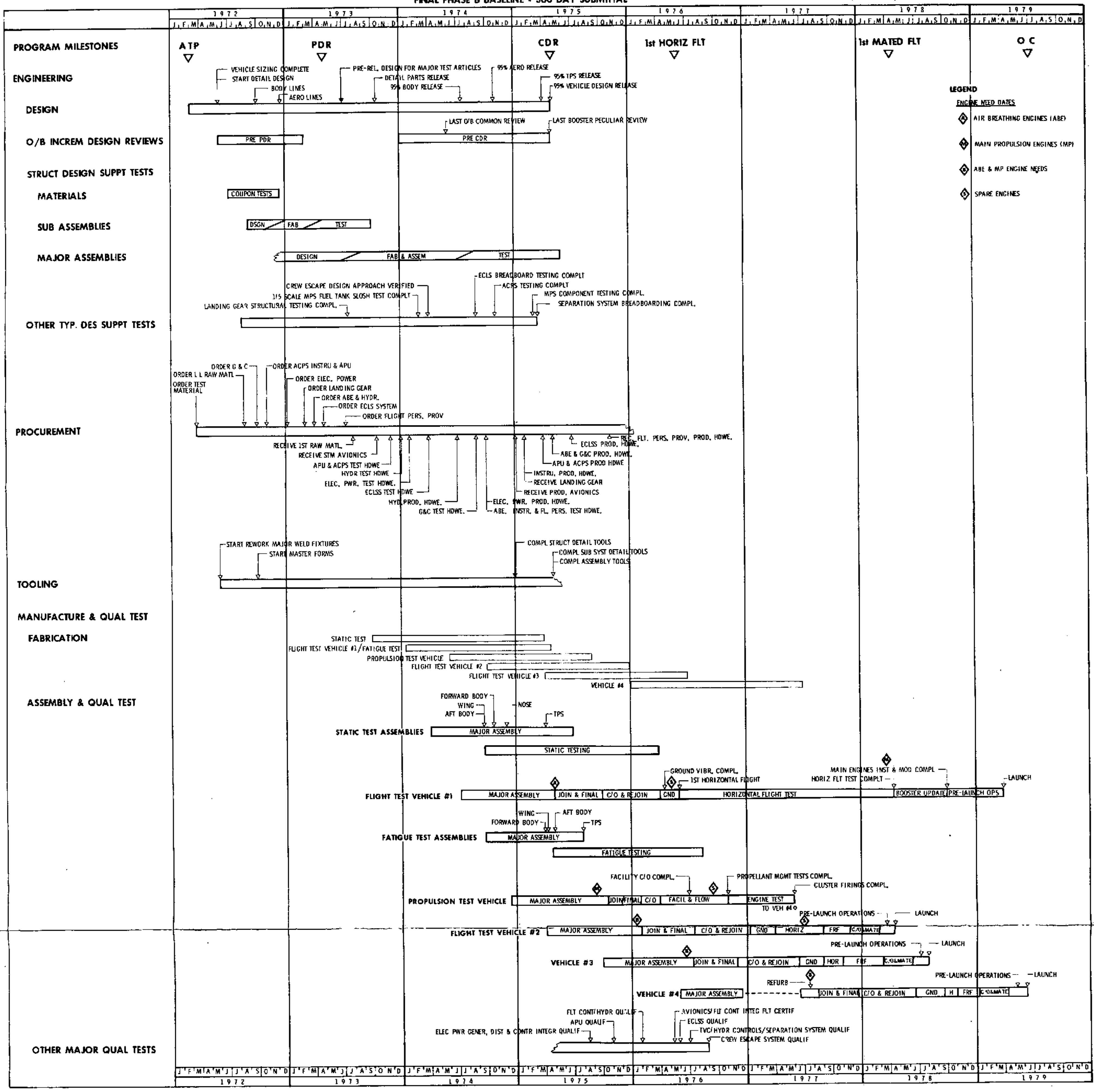
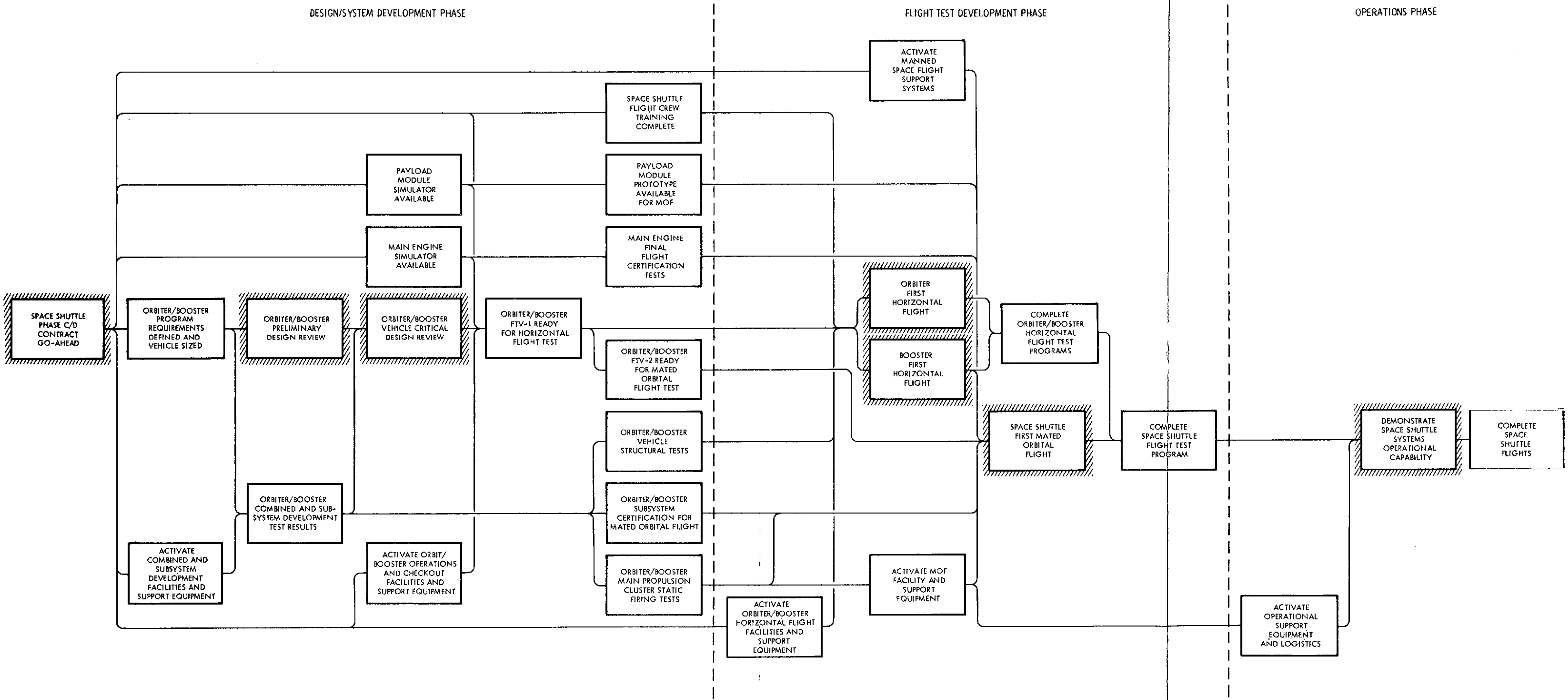


Figure 7-1. Phase C/D Booster Schedule



2-5 A

2-5 B

Figure 2-2. Space Shuttle System Development Logic Summary